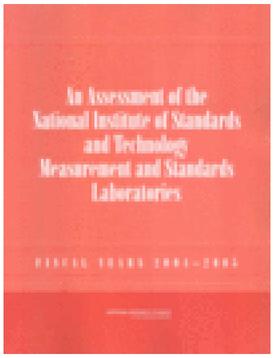

An Assessment of the National Institute of Standards and Technology Measurement and Standards Laboratories: Fiscal Years 2004-2005

National Research Council

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

FISCAL YEARS 2004–2005

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

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Preface

The mission of the National Institute of Standards and Technology (NIST) Measurement and Standards Laboratories is to promote 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 charge of the National Research Council's (NRC's) Board on Assessment of NIST Programs is to provide biennial assessments of the scientific and technical quality, relevance, and effectiveness of the NIST Measurement and Standards Laboratories. This assessment focuses on the technical merit of the laboratory programs relative to the current state of the art worldwide, the effectiveness with which the laboratory programs are carried out and the results disseminated, and the degree to which the laboratory programs are meeting the needs for which they are intended. In addition, the Board was specifically asked by the NIST Director to consider the adequacy of the laboratories' facilities, equipment, and human resources, insofar as they affect the quality of the technical programs and the effectiveness with which the laboratories meet their customers' needs.

The Board currently consists of 22 leading scientists and engineers whose experience collectively spans the major topics within the scope of NIST. Seven panels, one for each of NIST's laboratories,[1] report to the Board; 15 of the Board members also serve on panels, 7 of them as panel chairs and 8 as panel vice chairs. The panels range in size from 17 to 24 members, whose expertise is tailored to the technical fields covered by the laboratories that they review. In total, 153 experts participated, without compensation, in the 2-year process that led to this report.

The Board and panels are appointed by the NRC with an eye to assembling balanced slates of experts without conflicts of interest and with balanced perspectives. The 153 experts include current and

[1]The seven NIST laboratories are the Building and Fire Research Laboratory, the Chemical Science and Technology Laboratory, the Electronics and Electrical Engineering Laboratory, the Information Technology Laboratory, the Manufacturing Engineering Laboratory, the Materials Science and Engineering Laboratory (which includes the NIST Center for Neutron Research), and the Physics Laboratory.

former executives and research staff from industrial research and development laboratories, leading academic researchers, and staff from other national government laboratories. Fifteen of them are members of the National Academy of Engineering, two are members of the National Academy of Sciences, and a number have been leaders in relevant professional societies. Biographical information on the Board members, along with a listing of the panel membership, appears in Appendix B.

The current report is the first biennial assessment by the Board. In the past, since 1959 when the assessment process commenced, annual reports had been produced. Like the earlier reviews, this report contains the Board's judgments about the quality of NIST's work. The amount of information that is funneled to the Board, including the consensus evaluations of the recognized experts who make up the Board's panels, provides a solid foundation for a thorough peer review.

A rich set of interactions supports the judgments of the Board, which are summarized in this report. This peer review of NIST is based on a large amount of information received from NIST staff and on interactions with them. Most of the information exchange occurs during annual visits by the panels to the respective NIST sites. This information, gathered during collegial and generally unstructured exchanges between panel members and NIST scientific and technical staff, is supplemented by written material provided by the NIST laboratories to panel members prior to or during the site visits. Additionally, each panel convenes biennially to deliberate on its impressions and findings and to develop formal conclusions and recommendations that are subsequently communicated to the Board.

Overview briefings by NIST management keep the panels up to date on NIST's technical planning, significant events, highlighted accomplishments, and resources. Technical briefings focus on the scientific and technical goals, strategies, methodologies, and results of selected projects at each laboratory. Briefings are targeted with an eye toward coverage of a representative sample of each laboratory's work over the 2-year assessment cycle. Ample time during both overview and technical briefings is devoted to discussion, both to clarify a panel's understanding and to convey the observations and impressions of individual panel members to NIST's scientists and technical staff.

The Board and panels applied assessment criteria organized by four categories:

1. *Technical quality and merit:* criteria that include the extent to which the work demonstrates high technical quality and merit; compares to current state-of-the-art capabilities worldwide; reflects a broad understanding of comparable work being done elsewhere (other government laboratories, universities, and industry); demonstrates links between NIST researchers and the external community; and balances anticipatory, longer-term research and activities that respond to immediate customer needs.

2. *Relevance:* criteria that include the extent to which the laboratories are pursuing unique measurement and standards activities that clearly support high-priority national needs; are performing work that is clearly tied to NIST objectives; are performing work that is focused on clear and compelling industry/customer needs; are scaling programs appropriately to meet the technical problems being addressed; and are moving programs at a pace and in a direction that is well matched to current and emerging customer needs.

3. *Effectiveness:* criteria that include the extent to which the laboratories are regularly implementing sound and effective techniques and practices for delivering products and services; make the results of the laboratory work program readily available to customers; and conduct work that is likely to have consequential, long-term impact.

4. *Adequacy of facilities, equipment, and human resources:* criteria that include the extent to which the available scientific and technical competencies are adequate to achieve success; the state of the equipment and facilities is adequate to meet program objectives and customer needs; and the laboratory is sustaining the technical competencies and capacity to respond quickly to critical issues as they arise.

In addition to the primary assessment criteria outlined above, in certain circumstances the Board may judge it useful to explore other issues, either to garner more information relevant to the primary criteria or to deal with specific projects or lines of investigation under way within a laboratory. These considerations include collaboration and crosscutting work within a given NIST laboratory, project-specific methodological considerations underlying the quality and merit of products and results, and project-level technical planning.

The Board and its panels are supported by NRC staff, who interact with NIST, the Board, and the panels on an ongoing basis to ensure that the Board and panels receive the information they need to carry out their assessments. Board and panel members serve for finite terms, generally between 2 and 6 years, staggered so that there is regular turnover and a refreshing of viewpoints.

In May 2005, the Board met for 2 days to share members' summaries of their panels' findings; this report represents the Board's consensus findings and recommendations. The Board's aim with this report is to provide guidance to the NIST Director that will help NIST sustain its process of continuous improvement. To that end, the Board examined its extensive and detailed notes from the many Board, panel, and individual interactions with NIST over the fiscal year 2004-2005 period and distilled from them a short list of the main trends, opportunities, and challenges that merit attention at the level of the NIST Director. Specific NIST projects are used to illustrate these points when it is helpful to do so, but the Board did not aim to present the Director with a detailed account of 2 years' worth of interactions with bench scientists. The draft of this report was subsequently honed and reviewed according to NRC procedures before being released.

The report begins with a synopsis intended for NIST stakeholders and an introductory chapter that summarizes the Board's institution-wide assessment of the NIST Measurement and Standards Laboratories. The synopsis and introductory chapter focus on key themes that apply across the seven laboratories; they are not intended as a distillation or highlighting of the findings described in the subsequent seven chapters, each of which addresses a specific laboratory. The reader is encouraged to peruse those chapters for key conclusions and recommendations specific to each laboratory.

Throughout this thorough 2-year assessment, the 153 expert volunteers have devoted considerable attention, time, and energy to attending annual visits to NIST laboratories; carefully examining materials presented to them by NIST; very actively interacting with the NIST staff; meeting with one another to deliberate diligently and to develop formal findings, conclusions, and recommendations; formulating written material documenting their findings; and reviewing one another's written drafts. The panel chairs and vice chairs, as well as the at-large members of the Board, have also attended Board meetings and worked in a dedicated fashion to develop this report; their untiring efforts are gratefully acknowledged. NIST management and staff have, at all levels, graciously and openly discussed their work with these expert visitors. The Board acknowledges with gratitude their hospitality and their willing and consistent support of its efforts.

Kenneth H. Keller, *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:

William B. Bridges, California Institute of Technology,
Gregory R. Choppin, Florida State University,
T. Dixon Dudderar, Chatham, New Jersey,
Theodore V. Galambos, University of Minnesota,
James N. Gray, Microsoft Corporation,
John W. Lyons, National Defense University,
Stephen M. Pollock, University of Michigan,
Donald E. Ross, Laurel Hollow, New York, and
Richard S. Stein, University of Massachusetts, Amherst.

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 General Alton D. Slay, Slay Enterprises, Inc. 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

Synopsis of the 2004-2005 Assessment

This report, *An Assessment of the National Institute of Standards and Technology Measurement and Standards Laboratories: Fiscal Years 2004-2005,* is the latest in a series of independent peer reviews of the National Institute of Standards and Technology (NIST) laboratories conducted by the National Research Council (NRC) since 1959. Although commissioned by NIST as part of its process for continuous improvement, this assessment was conducted and written by a standing board of the NRC that is independent of NIST. This report is based on the observations and professional judgment of 153 independent, pro bono experts chosen by the NRC for their relevant technical expertise. Most of these scientists and engineers visited NIST three times during the 2 years of this assessment period for a total of 6 days, to gather information and engage in extensive, in-depth discussions with NIST management and staff. Through this intensive process, the Board sampled enough programs to assess the technical quality of the seven NIST Measurement and Standards Laboratories (MSLs).

Chapter 1 of this report contains an institution-wide assessment of the NIST MSLs. Chapters 2 through 8, each of which addresses one of the seven MSLs, contain a wide range of observations and recommendations developed from the extensive fact-finding. In this synopsis, the Board presents the aspects of its assessment that should be of interest to the community of NIST stakeholders.

The Board is very impressed with the technical quality of NIST's intramural work. NIST carries out in a superb fashion an absolutely vital role in supporting as well as facilitating the further development of the technological base of the U.S. economy. Its personnel and scientific programs are, by scientific measures, among the best in the world, and its explicit and continuing attention to the needs of its customers keeps it alert to the changing technological environment to which it must be responsive.

NIST's programs continue to evolve in an impressive fashion, driven both by the expansion in its authority and responsibility that took place in 1987 and 1988,[1] to which it has responded admirably, and

[1]The change occurred with the transformation of the National Bureau of Standards into the National Institute of Standards and Technology.

by the very rapid rate of change being experienced in global scientific and technological driving forces for economic growth and social change. This has required that it become a more entrepreneurial, outward-looking, customer-focused research organization with core competencies and the agility to respond quickly and effectively to emerging national needs. It is clearly meeting that requirement extremely well.

At the same time, NIST must continue its traditional scientific efforts in metrology and standards development. Laboratory organization, staffing, and project selection are all affected by the need to maintain a balance between these two types of activity. Many of the comments in this report relate to an assessment of the largely successful effort at NIST to achieve that balance as well as the identification of ways to perpetuate and improve upon it.

The rapid rate of change in scientific and technological driving forces affects NIST in several ways. First, it places demands on NIST to develop new metrological tools that can be used effectively at shorter timescales and finer length scales or to make measurements in entirely new kinds of systems. Second, to meet the national need and NIST's goal that it remain among the world's best laboratories of its kind, it must be a first mover in applying new science and technology (S&T) to the development of new metrological approaches. And, third, since the most rapid S&T developments occur at the boundaries between disciplines, there is an increasing need for multi- and interdisciplinary approaches that challenge the traditional disciplinary structures in all research institutions, including NIST. A number of comments in this report address ways of dealing with these challenges.

The following general observations of the Board pertain to the NIST Measurement and Standards Laboratories as a whole:

1. NIST has undergone a remarkable transformation in little more than a decade and a half from an organization devoted to producing excellent science and standards in an orderly, incremental fashion using a single-principal-investigator mode of operation to an entrepreneurial, outward-looking, customer-focused research organization whose core competencies and newly developed agility have responded quickly and effectively to emerging national needs. NIST serves a vital role in supporting the further development of the technological base of the U.S. economy, and it does so superbly.

2. NIST appears, in most respects, to be moving very well in addressing the focus areas identified in its 2010 Strategic Plan (NIST, 2004), particularly with respect to nanometrology and homeland security. Its work in the areas of the biosciences and health has had a very good start, but in order for this work to make broad and continuing contributions consistent with NIST's own standards of excellence, the Board recommends that those two focus areas be considered as distinct from each other.

3. The Board also recommends that NIST undertake comprehensive, cross-laboratory planning efforts in both the biosciences and health to identify the subset of issues that it is best positioned to address and to develop coordinated approaches to addressing those issues. It is noted that both of these fields depend strongly on scientists with interdisciplinary training, so NIST's planning in this field must be tightly linked to staff development.

4. The Board notes, with strong approval, the continued growth of institutional collaborations between NIST and other organizations, which are expanding NIST's capacities and establishing useful institutional and professional relationships. The Board recommends, however, that criteria be further developed and/or more clearly communicated to staff concerning the circumstances under which patent protection is to be sought for NIST products. It is important both for NIST staff and for collaborators from other institutions to have a consistent perspective on intellectual property issues or to develop procedures that recognize and respect institutional differences so as to smooth the collaborations.

5. NIST is clearly faced with the difficult task of balancing its traditional roles in metrology and

standards development with its newer, broader roles in technology development related to national needs. The Board observes that for the most part this is being done quite well. It suggests, however, that clearer criteria need to be developed for the setting of programmatic and project priorities that will continue to achieve that balance in the long run, and that can be used as well to develop long-term staffing plans.

6. The design of NIST's current Web site does not allow for easy access to the wealth of information that the MSLs are generating. This is a particular problem for occasional customers, who are likely to comprise an increasing fraction of NIST's constituency. The Board recommends that NIST treat Web site development as a high priority in the next 2 years.

7. The Board was specifically asked by the NIST Director to consider the adequacy of the laboratories' facilities, equipment, and human resources, insofar as they affect the quality of the technical programs and the effectiveness with which the laboratories meet their customers' needs. Therefore, the Board notes that while NIST management has worked creatively to maintain the quality of the laboratories through a period of sometimes decreasing or at least uncertain funding, in the long run it cannot continue to do so. That is, NIST will not be able to respond to all that it is being asked to do and also to maintain its quality if action is not taken to reverse its loss of staff.

8. Finally, the Board notes that it has proposed that NIST give consideration to reviewing the NIST Boulder operation as a single, integrated entity in the next biennial assessment, which would be a departure from the past. Although this idea emerged as a possible way to simplify the assessment process, it raises the issue of whether treating Boulder as an integrated entity might have programmatic advantages. The Board has reached no conclusion on this point, but poses it as a question to NIST management.

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

1

Institutional Assessment

INTRODUCTION

A summary of this Board's technical assessment of the programs of the National Institute of Standards and Technology (NIST) can well begin with a straightforward statement: NIST carries out in a superb fashion an absolutely vital role in supporting as well as facilitating the further development of the technological base of the U.S. economy. Its personnel and scientific programs are, by scientific measures, among the best in the world, and its explicit and continuing attention to the needs of its customers keeps it alert to the changing technological environment to which it must be responsive.

NIST's programs continue to evolve in an impressive fashion, driven both by the expansion in its authority and responsibility that took place in 1987 and 1988, to which it has responded admirably, and by the very rapid rate of change being experienced in global scientific and technological driving forces for economic growth and social change. The responsibilities that accompanied the transformation of the National Bureau of Standards into the National Institute of Standards and Technology gave rise to one of NIST's key challenges: to take on a much broader role in "supporting the development, wide diffusion, and efficient use of advanced technology . . . throughout the private, public, and non-profit sectors" (NIST, 2004, p. 1). Assuming this role has required that it become a more entrepreneurial, outward-looking, customer-focused research organization with core competencies and the agility to respond quickly and effectively to emerging national needs. It is clearly meeting that requirement extremely well.

At the same time, NIST must continue its traditional scientific efforts in metrology and standards development. Laboratory organization, staffing, and project selection are all affected by the need to maintain a balance between these two types of activity. Many of the comments in this report relate to an assessment of the largely successful effort at NIST to achieve that balance as well as the identification of ways to perpetuate and improve upon it.

The rapid rate of change in scientific and technological driving forces affects NIST in several ways. First, it places demands on NIST to develop new metrological tools that can be used effectively at shorter timescales and finer length scales or to make measurements in entirely new kinds of systems. Second, to meet the national need and NIST's goal that it remain among the world's best laboratories of its kind, it must be a first mover in applying new science and technology (S&T) to the development of new metrological approaches. And, third, since the most rapid S&T developments occur at the boundaries between disciplines, there is an increasing need for multi- and interdisciplinary approaches that challenge the traditional disciplinary structures in all research institutions, including NIST. A number of comments in the following sections of this chapter and in the chapters on the individual laboratories address ways of dealing with these challenges.

NIST's effectiveness in serving its customers and its impact on the nation's competitiveness depend on how well its measurements capabilities, standards, and process guidelines are disseminated to various user communities and adopted by them. This, in turn, is affected by changes occurring in the U.S. industrial structure and by the emergence of new national concerns. For example, as noted in a report recently prepared by the National Research Council (NRC, 2002) for NIST, the central research laboratories of many large corporations have been phased out, long-term basic research by those companies has been markedly curtailed, and technological development has been outsourced. By contrast, technological innovation by small start-up companies has been steadily growing, new partnerships have developed between universities and industry with close attention to protecting and sharing intellectual property rights, and various networks and consortia have been created that play a significant role in determining the direction of research and development. Each of these developments creates a shift in NIST's customer base to a certain extent, in some instances requiring communication with audiences that have little experience in dealing with NIST, in other cases requiring that information be packaged and delivered differently.

Public safety and environmental protection are among the most obvious of the new national concerns to which NIST must now respond. It has been relatively easy for NIST to undertake those public safety projects that are identified as related to "homeland security" because of the governmental and public interest in the topic. The urgency of the concern, the new organizations that have been developed to deal with it, and the prominence of security efforts in many of NIST's "customer" organizations give visibility and build interest in any projects related to homeland security and thus make it easier for NIST to disseminate its results to interested parties.

There is also public concern for environmental protection, and there is evidence throughout NIST of activities related to this issue. However, the customers for NIST's products in this area are much more dispersed among, for example, primary energy producers, manufacturers, environmental and agricultural agencies at both state and federal levels, architects, builders, and nongovernment organizations. Therefore, it is considerably more difficult to systematically connect NIST's output in environment-related science and technology with those who most need to have it available. This represents another challenge that would benefit from the development of a comprehensive dissemination strategy.

If the restructuring of the industrial base and the emergence of new, very broad issues of national concern represent new challenges in dissemination, advances in information technology and the availability of the World Wide Web and other internets and intranets offer new and effective ways to disseminate the vast amounts of useful information being generated at NIST. Some laboratories—for example, the Information Technology Laboratory (ITL)—are making good use of these new capabilities, but in general it appears that further focused attention to Web-based communication is warranted.

One last introductory comment relates to the assessment of the adequacy of NIST's staffing, which is one of the elements in the charge to this review Board. In panel after panel, in laboratory after laboratory, a common theme that emerged was admiration for the creative efforts of NIST management at all levels in coping with increasingly constrained resources. These efforts are directed at taking on new areas of responsibility while continuing to meet long-standing demands on their programs, working to maintain the morale of scientists whose career stability is constantly threatened by budget uncertainties, and attempting to make and carry out long-term plans for laboratory evolution while dealing with year-to-year budget volatility and, at least recently, a downward trend. At the same time, panelists and Board members noted that these managerial efforts can be no more than holding actions and that a continuation of this pattern must, over time, take its toll on the quality and quantity of NIST's efforts. Again, there was virtual unanimity among Board and panel members that NIST's work is critical to America's technological base and international competitiveness and that, were its quality to be permanently damaged by underinvestment, the nation would suffer. The arguments for this conclusion are expanded on toward the end of this chapter in the section "Adequacy of Staff Resources" and are included as well in the discussions of the individual laboratories.

The following sections identify and discuss a number of broad themes and general issues that emerged in the course of this comprehensive technical review of NIST's impressively wide range of programs. These sections are not intended to summarize the several chapters that follow, each of which deals with one of the laboratories. Those chapters stand on their own. Instead, the aim is to identify issues that are best dealt with institution-wide and that have significant potential for furthering NIST's health and effectiveness.

STRATEGIC FOCUS AREAS

The NIST 2010 Strategic Plan identifies several areas in which NIST perceives special challenges and opportunities, including nanometrology, biosciences and health, and information/knowledge management. The plan also points out that "new demands and government priorities for public safety and security will . . . exert a strong influence on NIST's program portfolio" (NIST, 2004, p. 8).

These are clearly areas of national importance, and it was apparent, as noted in several of the chapters on individual laboratories, that there is a growing number of projects in these areas. However, there are organizational challenges in dealing effectively with new areas such as these—areas that draw in part on existing competencies while also requiring that those competencies be strategically combined and sometimes augmented. These projects do not map neatly to existing disciplinary divisions nor, in some cases, to traditional areas of strength at NIST.

The Board notes, with strong approval, that NIST is working to meet this challenge in a number of ways. Each Strategic Working Group has representatives from each laboratory. In addition, certain of the laboratories are expanding their reliance on matrix management approaches (see, for example, Chapters 3 and 6) in order to focus on cross-disciplinary themes or to promote cross-disciplinary interactions. Also, each of the laboratories has some form of matrix management through programs, centers, or offices that address problems requiring expertise from multiple groups or divisions. Indeed, the Manufacturing Engineering Laboratory (MEL) has a laboratory-wide matrix management system. There are also efforts to develop cross-laboratory collaborations, although more remains to be done in this respect (see the comments below on biosciences and health).

The strategic focus on homeland security appears to be making particularly effective progress, in all likelihood because of the opportunities and strong sense of urgency and focus created by the intense public interest in the subject and the availability of funding. Most of the laboratories have undertaken security-related projects, some within a single group and some requiring matrix-managed approaches or cross-laboratory coordination. The comprehensive and multidimensional investigations conducted by NIST in relation to the World Trade Center attacks of 2001 provide examples of all of these approaches.

Additional examples of cross-laboratory collaboration include the Office of Microelectronics Programs and the Office of Law Enforcement Standards (within the Electronics and Electrical Engineering Laboratory [EEEL]); the Computer Security, Biometrics, and NIST Voting Activities Resource Centers (within ITL); the NIST Combinatorial Methods Center and the Center for Theoretical and Computational Materials Science (within the Materials Science and Engineering Laboratory [MSEL]); and the Quantum Information Program (within the Physics Laboratory [PL]).

It was also evident that there is significantly expanded activity in nanometrology and related fields. In contrast to the driving forces behind efforts in the area of homeland security, the driving force for these efforts is less societal demand than the push of new technological potential. Because the term nanotechnology is a very broad rubric encompassing a number of different technological developments, close coordination of these efforts is needed less than it is needed in other areas. Individual projects can thrive, as indeed they appear to be doing in several of NIST's laboratories. Various nanotechnology thrust directions are, of course, closely attuned to NIST's traditional areas of expertise in materials, manufacturing, computing, atomic-scale physics, and electronics—which facilitates the rapid and comprehensive expansion into this area that the panels observed.

The strategic area of biosciences and health contrasts with nanotechnology in a number of respects. Clearly, excellent work in this field is already under way in a number of NIST's laboratories, and NIST has an important role to fill in exploiting the breakthroughs in many facets of the biosciences. However, this has not been a priority area for NIST in the past, and the Board believes that it will be necessary for NIST to take a comprehensive approach to planning, organizing, and staffing its expanded role in this area if it is to optimize its effectiveness.

The NIST Strategic Plan properly identifies biosciences and health as a focus area, but the Board believes that the first challenge is, in fact, to decide on just what NIST's focus will be in this area. It is not clear that lumping health and biosciences together in a single category is the best approach. In fact, it is already apparent that some of the activities under way might be categorized under one or the other of these two terms but are quite different in their goals and only tenuously related technically. Thus, for example, the very useful ongoing effort in ITL to develop standardized medical records, which might well be viewed as part of a health focus, has almost no connection to work such as characterizing the biocompatibility properties of polymer surfaces, which is being carried out in MSEL, or protein-folding dynamics studies in the Chemical Science and Technology Laboratory (CSTL).

Indeed, despite the fact that health care and the health care industry obviously draw on advances in the biosciences, the trend appears to be in the direction of separating the two areas. For example, universities such as the Massachusetts Institute of Technology have established departments of biological engineering that are separate from their departments and programs in biomedical engineering. In other schools, basic biological sciences and biotechnology have for some time been separate from basic medical sciences and medical technology. This separation reflects not so much an emphasis on the division between fundamental and medically applied biosciences as a desire to exploit linkages to other applications that depend on the biosciences, including agriculture, fine chemical production, ecology, environmental protection, and even bioterrorism. Treating health and biosciences as separate strategic foci would allow each area to identify goals, strategies, and activities that are focused and draw on NIST's comparative advantage.

There is considerable opportunity and need for interlaboratory collaboration in both health and biosciences, and there is already evidence at NIST that such collaboration has begun. A recent survey by the NIST Biosystems and Health Strategic Working Group (VCAT, 2004a, 2004b) identified 148 NIST projects in the health sciences, with projects being conducted at each laboratory. In the biosciences, interesting and effective collaborations are under way between CSTL and ITL on molecular imaging, between MSEL and CSTL in tissue engineering, and between EEEL and CSTL in DNA analysis using microfluidics. In addition, NIST has played a significant role in the development and maintenance of the Protein Data Bank, the world's most complete repository for data on the three-dimensional structure of proteins and nucleic acids. (However, as noted in Chapter 3, on CSTL, the Board has great concern that NIST is no longer part of the consortium that manages this database, an action that the Board views as misguided.)

Other work under way in individual laboratories seems very likely to lead to interlaboratory collaborations in the near future: for example, the EEEL work on biopolymer transport through nanometer-scale pores, the CSTL work on the uses of gene expression profiling, and the MEL work on biosurveillance interoperability standards. Beyond these activities, opportunities have been identified (VCAT, 2004b) in systems biology and nanobiotechnology in which NIST could make a significant contribution.

In health-related areas, CSTL and MSEL are collaborating on developing combinatorial approaches to identifying and optimizing the biocompatible properties of polymer surfaces for use in tissue scaffolds. The PL's Ionizing Radiation Division is involved in diagnostic medical imaging, and CSTL's Analytical Chemistry Division has ongoing work in microfluidic separations as well as cell-based assays and immunoassays. And here, too, significant new opportunities for several of NIST's laboratories have been identified (VCAT, 2004b) in various aspects of bioimaging, medical robotics, and drug delivery.

The biosciences present very complex staffing problems for NIST, both because they have not been a primary focus in the past and because work at the forefront of this field relies more heavily on interdisciplinary than on multidisciplinary research. The latter term refers to crosscutting research in which researchers with distinct scientific backgrounds work collaboratively, but separately, on different aspects of the same problem. The former term refers to research in which the questions must be posed as an integrated whole, the research is not easily subdivided into disciplinary components, and the researchers themselves must be considerably more familiar with all aspects of the problem.

Multidisciplinary research yielded interesting and useful findings in the early years of collaboration between physical and biological scientists. However, as pointed out in a recent workshop (NRC, 2002) that brought together physical and biological scientists to identify research opportunities at the interface between their two fields, biosciences and bioengineering have matured, and the most interesting and important problems must be approached by interdisciplinary teams (BLS/BPA, 2004). There are many examples in the fields of proteomics, physiomics, nanobiology, enzyme kinetics, cellular motility, signal transduction, hybrid organ and tissue engineering, and biological energy production, among many others, that illustrate this point. In light of this increasing need for interdisciplinary approaches, it is likely that NIST's further involvement in these areas will require some altered or augmented staffing in addition to an expansion of interinstitutional collaborations.

Taken together, these observations suggest that, in the very near future, NIST should undertake comprehensive, cross-laboratory planning in the separated areas of bioscience and health, to identify its comparative advantages in order to focus its efforts, to expand the cross-laboratory collaborations that have already begun, to establish its staffing needs, and to develop a strategy for meeting those needs.

INTERINSTITUTIONAL COLLABORATIONS

Panelists took note of the several interinstitutional collaborations in which NIST laboratories are involved: some are long-standing, such as that of JILA (the Joint Institute for Laboratory Astrophysics, with the University of Colorado) and the Center for Advanced Research in Biotechnology (with the University of Maryland); some are relatively new and rapidly expanding, such as the collaboration with the Hollings Marine Laboratory in South Carolina. Panelists' comments were uniformly positive about the value of these relationships, which offer opportunities to augment the in-house expertise at NIST, allow NIST to tackle a broader range of questions in an integrative way, and expand the potential synergies that are the hallmark of multidisciplinary research projects. They also increase NIST's visibility and forge connections with professional colleagues who are not only potential collaborators, but members of NIST's user communities. The Board encourages a continuation and expansion of these kinds of relationships; discussions with NIST staff suggest that this is their intention.

As such interinstitutional collaborations continue to grow, it would be useful to address the issue of intellectual property (IP) rights arising out of joint activities. The Board is aware that clear guidelines exist at NIST concerning intellectual property rights. The guidelines cover the creation, protection, and allocation of IP rights in cooperative research and development agreements (CRADAs); situations in which guest researchers are involved; and cases in which proprietary information is shared in the context of a project. However, the guidelines have been less clearly conveyed to staff with respect to the criteria to be used in order to determine what kinds of developments should be targeted for IP protection. Several panelists reported that there continues to be wide variation in how professional staff view this issue—a not-unusual situation in either government or university laboratories.

Since passage of the Patent and Trademark Law Amendments Act, known as the Bayh-Dole Act, in 1980, universities and, to a large extent, their faculties have become more sensitive to both the economic potential and the ultimate social value of securing IP rights. This awareness has led to a sea change in perspective concerning IP and changes in operating procedures to preserve these property rights. Some (although not all) of the arguments supporting preservation of these rights would apply equally in NIST's setting, but it is not clear that there has been a similar shift in the perspective of NIST scientists. The resulting difference in perspective appeared to the Board to be a source of friction in certain instances when NIST scientists and their collaborators from other institutions were working together.

Given the high potential value of joint NIST-university efforts, the Board believes that it would be useful to address once again the issue of IP rights. This effort should include ensuring that existing procedures are well understood by all NIST staff, but it should place greater emphasis on clarifying guidelines that explain when patent protection should be sought. In the process of amplifying on the patent policy, it is important to convey the reasoning underlying the Bayh-Dole Act with respect to the social value of establishing IP rights. Broader understanding of this reasoning is likely to establish a greater commonality of views between NIST and the institutional partners with which it is working. The Board believes that addressing this issue would go far in ensuring transparency, smoothness, and clarity of expectations in these joint programs.

NIST AT BOULDER

NIST's operation in Boulder, Colorado, comprises activities associated with all of the laboratories but two: the Building and Fire Research Laboratory (BFRL) and MEL. In certain cases (EEEL, MSEL, and PL), whole divisions or at least project groups are located there; in other cases (e.g., ITL), staff members with similar areas of interest are divided between the Gaithersburg, Maryland, campus and Boulder. The practice in the past, and continued in this assessment cycle, was to review Boulder programs (when appropriate) as part of the individual laboratory reviews, either through separate subpanel visits to Boulder or by videoconferencing (as was done, for example, in this cycle in reviewing the quantum computing program in ITL). The Board would like to raise for discussion the question of whether there would be merit in reviewing the Boulder campus of NIST as a single, coherent unit in the future.

The Boulder operation presents unique challenges and opportunities that might be more adequately addressed in an integrated way. Boulder benefits from its proximity to other federal laboratories, its physical environment, and its close collaboration with the University of Colorado. At the same time, its physical distance from the Gaithersburg operation cuts down on the opportunities for day-to-day interactions between laboratory colleagues at the two sites and introduces challenges to effective joint management.

Thus, the Board is raising the question of whether it would not be appropriate to undertake a comprehensive review of the Boulder operation to determine whether some strategic choices might be made to restructure Boulder's efforts to build on its comparative advantages and minimize its inherent disadvantages. Information technology can, of course, overcome many of the disadvantages of distance. Nevertheless, in view of other comments in this report concerning the importance of strategic focus areas and the promise of cross-disciplinary collaborative efforts, there would appear to be significant potential for experimenting with alternative organizational and topical configurations at Boulder. However, the Board would not prejudge the outcome of a more methodical investigation of the possibilities by NIST itself.

BALANCING NEW STRATEGIC FOCI, NEW SCIENCE, AND TRADITIONAL ROLES

It is clear from NIST's Strategic Plan, from discussions during panel site visits, and from comments in Chapters 2 through 8 on the individual laboratories that balancing old and new activities is a major challenge for NIST. The Board concurs that maintaining a balance between new strategic foci and traditional roles is a proper goal, and one largely being met in the activities under way in the individual laboratories. When there appeared to panel members to be an imbalance, it was noted in the relevant laboratory chapters.

The balance between new strategic foci and traditional roles is an important element in maintaining the technical quality of the laboratories. The practical expertise developed by NIST over the years through its metrology work is one of its unique strengths. Useful contributions to new areas are more likely to occur with a staff that is experienced in both the needs and the applications of their fields. In addition, the effective transfer of new technologies to the user community is best achieved when the laboratories have developed strong connections to and credibility with those communities, both of which are developed and maintained by NIST's more traditional services.

A major question is what general principles might best be applied in achieving the desired balance of activities. In the view of the Board, one valuable principle would be to emphasize activities that bring new scientific approaches to traditional metrological and standards-setting tasks. There are many examples at NIST of ways in which this is being done quite successfully. The new kilogram force standard and the facility for Simulated Photodegradation by High Energy Radiant Exposure (SPHERE) are worthy of special mention, and a number of others are cited in Chapters 2 through 8 and in other sections of this chapter.

There are, of course, other cases in which activities in metrology or standards setting are not necessarily groundbreaking in their science or technology but nonetheless are unique in the nation and important to customer communities. NIST is appropriately maintaining these kinds of activities. More problematical are service functions that, in principle, could be carried out by other organizations. These include routine instrument calibrations or relatively minor updating of standards. Such functions should be phased out, except in the few instances in which they contribute in other ways to maintaining NIST's goals. For example, if maintaining certain service activities enables NIST to retain career scientists who also contribute to strategic focus efforts or to the development of new metrology science, then they serve an important function. Similarly, if the activities represent the only way to keep NIST closely connected to its customer communities, they may be worthwhile even if they are not innately of the highest priority.

In the end, many of these questions bear on long-term staff planning issues. The Board believes that each of the laboratories should explicitly undertake this kind of planning. It is an issue made more complicated, but all the more necessary, by the unfortunate short-term volatility that NIST has experienced in its financial support. Particularly under such circumstances, planning to preserve the long-term strength and continuity of laboratory functions becomes vital, and almost all other quality outcomes depend on its success. Further discussion of this issue is presented in the section below entitled "Adequacy of Staff Resources."

EFFECTIVE DISSEMINATION STRATEGIES

One of the great contributions that NIST makes to the American scientific and industrial base is the mass of information contained in the data sets generated by a number of its laboratories. A number of panelists remarked on the quality and extent of these data and their unique value. However, there was broad consensus that the NIST Web site is difficult to navigate, and therefore it is difficult to actually access the data being generated.

The problem is exacerbated by the various shifts in the locus of technological development in American society. The growing importance of medium and small entrepreneurial firms, the shift from permanent staffs to ad hoc or task-oriented teams in large corporations, and the growing role of professional societies in standards development all suggest that NIST cannot assume that its customers "know their way around" the laboratories. Therefore, NIST will have to provide much greater transparency if new or occasional users are to be able to access its products and data.

Information technologies, and particularly the Internet, are enormously valuable tools in dealing with this challenge, but it does not appear that NIST is presently exploiting those technologies in an optimal way. As noted above, the NIST Web site is not particularly easy to navigate or to use in an interactive way to obtain the wealth of data it has to share.

The Board suggests that NIST undertake a comprehensive development of its Web site to make it a useful resource for the public by providing a more easily searchable set of databases, a navigable reference library, and a hyperlinked connection to related sites. Because of the range of information that NIST has to offer, such a site should not depend on a single kind of search tool or only on an alphanumeric organizational structure. Indeed, NIST's competence in information technology suggests that it could itself be the developer of useful organizational and navigational tools. More effective use of the Web site would be of value not only in providing broader dissemination of NIST's products, but also in expanding the visibility of NIST itself to a public which, this Board believes, may not always understand or appreciate the contributions that NIST makes.

ADEQUACY OF STAFF RESOURCES

A recurring theme in Chapters 2 through 8 is that all programs are encountering serious difficulties as a result of both the actual reductions in professional personnel in the past few years and the uncertainties that have required management to plan for even more severe reductions in force that ultimately did not have to be executed. Although laboratory management has worked hard and responsibly to minimize the impact of these problems, a number of panels reported that morale has suffered, and it appears that the ability of laboratory management to create a balance between traditional and new activities has been hampered.

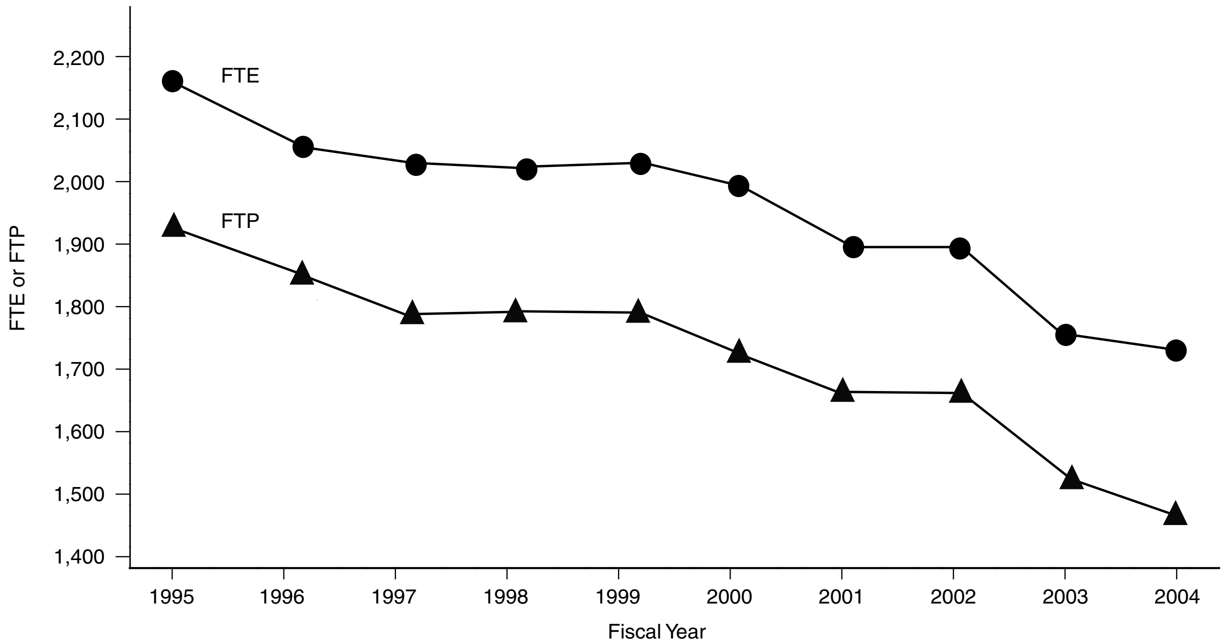

FIGURE 1.1 Aggregate staffing trends for the seven NIST Measurement and Standards Laboratories, 1995-2004. NOTE: FTP = full-time permanent employees; FTE = full-time-equivalent employees (FTP + other than FTP).

In Figure 1.1, aggregate data are presented for staffing trends for the seven Measurement and Standards Laboratories for the past decade. The data reflect a drop of about 23 percent in full-time-equivalent (FTE) personnel and about 21 percent in full-time permanent (FTP) employees. The staffing drop has been most precipitous since fiscal year (FY) 2002, with a decline of about 10 percent in FTE and 12 percent in FTP employees from FY 2002 through FY 2004. (Data on staffing trends for the individual laboratories are provided in Appendix A, Figures A.2 through A.8.)

It takes continuity and flexibility to maintain a laboratory of outstanding quality and to be able to respond to new needs and new opportunities. Both capabilities are threatened by the staffing trends of the past few years. As noted earlier in this chapter, NIST's goal of balancing its traditional mission with the new focus areas that arise from its expanding responsibilities and the nation's needs is not only appropriate to its mission, but necessary to maintaining its quality. The traditional activities and the individuals who engage in them are a source of experience, expertise, and connection to the user community; these activities and staff are invaluable in addressing new questions and new needs. New foci, however, provide a stimulus to new thought and encourage cross-disciplinary collaborations, which are frequently the locus of the most creative new science and technology.

The matrix management approaches now evident in two of the laboratories (CSTL and MEL) can operate effectively to allow both of these kinds of activities to continue. However, when total resources do not keep up with new responsibilities, management is forced to make unhealthy choices rather than to mount complementary projects. Both traditional and new activities suffer when that occurs.

Inadequate and/or volatile resources present an even more serious problem with respect to long-term staff retention and development. Adequacy of resources affects NIST's ability to meet the challenges to attract new talent (both to address new focus areas and to replace retiring senior researchers), to retain talented staff, to mentor and otherwise develop new staff to fulfill technical and leadership roles, and to continue to enrich its environment with visitors and temporary employees. To move into new areas, NIST must be able to attract new talent. For example, it will be very difficult to meet the goals for a new focus in the area of biosciences without the flexibility to attract professionals trained to work in an interdisciplinary environment. At the same time, being able to offer stability and to nurture the careers of professional staff is key to retaining them, which in turn is fundamental to the quality of the laboratory.

Visitors and temporary employees are major contributors to the quality of a laboratory, bringing in new ideas, establishing close working relationships that continue after the individuals have returned to their own institutions, and filling gaps in expertise in particular projects. Cutting back on visitors and temporary employees is one tempting strategy for coping with the decline in full-time staff in the short term, but it does not represent a viable long-term solution if the vitality of NIST is to be preserved. Within the constraints of funding, visitors and temporary employees should be hired and maintained on the basis of their technical contributions rather than as a means to address budgetary issues.

This is not to suggest that there are no practical choices that can be made in order to live within a constrained budget while preserving institutional quality. The Board encourages NIST to continue to identify programs that are of lower priority in each area and to phase them out. It is likely that such programs will be in the area of metrology services that other institutions are capable of providing and in which the opportunities are limited for introducing new science to the measurement technologies.

However, it is the opinion of this Board that NIST cannot continue to maintain its quality while continuing to undertake new foci, however important to the nation, without additional resources. As noted many times in this report, NIST has used its resources well and has created and maintained an excellent national facility that is serving America's industrial base well. The potential for it to increase its contributions further is there; the resources at present are not.

CONCLUSIONS AND RECOMMENDATIONS

This section is not intended to replace or summarize the comments and conclusions in the following chapters on the individual NIST laboratories. Those chapters reflect the very detailed and comprehensive reviews carried out by more than 150 scientists who participated in panel and subpanel laboratory visits and meetings over the course of the 2-year assessment period. It is instead a summary of the general observations made in this first overview chapter, which pertain to the NIST Measurement and Standards Laboratories (MSLs) as a whole. They are as follows:

1. NIST has undergone a remarkable transformation in little more than a decade and a half from an organization devoted to producing excellent science and standards in an orderly, incremental fashion using a single-principal-investigator mode of operation to an entrepreneurial, outward-looking, customer-focused research organization whose core competencies and newly developed agility have responded quickly and effectively to emerging national needs. NIST serves a vital role in supporting the further development of the technological base of the U.S. economy, and it does so superbly.

2. NIST appears, in most respects, to be moving very well in addressing the focus areas identified in its 2010 Strategic Plan (NIST, 2004), particularly with respect to nanometrology and homeland security. Its work in the area of the biosciences and health has had a very good start, but in order for this work to make broad and continuing contributions consistent with NIST's own standards of excellence, the Board recommends that those two focus areas be considered as distinct from each other.

3. The Board also recommends that NIST undertake comprehensive, cross-laboratory planning efforts in both the biosciences and health to identify the subset of issues that it is best positioned to address and to develop coordinated approaches to addressing those issues. It is noted that both of these fields depend strongly on scientists with interdisciplinary training, so NIST's planning in this field must be tightly linked to staff development.

4. The Board notes, with strong approval, the continued growth of institutional collaborations between NIST and other organizations, which are expanding NIST's capacities and establishing useful institutional and professional relationships. The Board recommends, however, that criteria be developed and/or more clearly communicated to staff concerning the circumstances under which patent protection is to be sought for NIST products. It is important both for NIST staff and for collaborators from other institutions to have a consistent perspective on intellectual property issues or to develop procedures that recognize and respect institutional differences so as to smooth the collaborations.

5. NIST is clearly faced with the difficult task of balancing its traditional roles in metrology and standards development with its newer, broader roles in technology development related to national needs. The Board observes that for the most part this is being done quite well. It suggests, however, that clearer criteria need to be developed for the setting of programmatic and project priorities that will continue to achieve that balance in the long run, and that can be used as well to develop long-term staffing plans.

6. The design of NIST's current Web site does not allow for easy access to the wealth of information that the MSLs are generating. This is a particular problem for occasional customers, who are likely to comprise an increasing fraction of NIST's constituency. The Board recommends that NIST treat Web site development as a high priority in the next 2 years.

7. The Board was specifically asked by the NIST Director to consider the adequacy of the laboratories' facilities, equipment, and human resources, insofar as they affect the quality of the technical programs and the effectiveness with which the laboratories meet their customers' needs. Therefore, the Board notes that while NIST management has worked creatively to maintain the quality of the laboratories through a period of sometimes decreasing or at least uncertain funding, in the long run it cannot continue to do so. That is, NIST will not be able to respond to all that it is being asked to do and also to maintain its quality if action is not taken to reverse its loss of staff.

8. Finally, the Board notes that it has proposed that NIST give consideration to reviewing the NIST Boulder operation as a single, integrated entity in the next biennial assessment, which would be a departure from the past. Although this idea emerged as a possible way to simplify the assessment process, it raises the issue of whether treating Boulder as an integrated entity might have programmatic advantages. The Board has reached no conclusion on this point, but poses it as a question to NIST management.

2

Building and Fire Research Laboratory

INTRODUCTION

The Building and Fire Research Laboratory (BFRL) has as its mission to "meet the measurement and standards needs of the building and fire safety communities." It accomplishes this through its vision of being "*the* source of critical tools—metrics, models, and knowledge—used to modernize the building and fire safety communities. [BFRL] programs are identified, developed, carried out, the results implemented, and consequences measured in partnership with key customer organizations" (BFRL, 2003).

The BFRL carries out its mission and vision by organizing its efforts in order to meet major goals. The four current major goals of BFRL are in the following areas:

1. High-performance construction materials and systems,
2. Enhanced building performance,
3. Fire loss reduction, and
4. Homeland security.

The laboratory staff is organized in three divisions, as shown in Appendix A:

- Materials and Construction Research Division (MCRD),
- Building Environment Division (BED), and
- Fire Research Division (FRD).

In addition, BFRL includes an Office of Applied Economics (OAE) and a codes and standards activity, which were also reviewed.

Appendix A also presents the staffing trends for the laboratory (see Figure A.2).

MAJOR OBSERVATIONS

In the past 2 years, BFRL has had an outstanding record of service to the country. These recent examples of excellent service build on a long-standing history of service to the country by this laboratory. The quality and effectiveness of the laboratory have been successfully called upon on several occasions. Based on this performance, new opportunities have been created for the future. Some of the major new initiatives of the laboratory in FY 2004-2005 were as follows:

- Responsibility for carrying out the provisions of the National Construction Safety Team Act of 2002 (NCSTA) was assigned by Congress to NIST, with BFRL as the lead laboratory.
- Under NCSTA, BFRL undertook a massive effort aimed at fully investigating the collapse of the World Trade Center's (WTC's) Twin Towers. It is noted that a separate advisory panel exists for this study.
- Also under NCSTA, BFRL investigated the Rhode Island nightclub fire that occurred in 2003.
- NIST was designated as lead agency for the National Earthquake Hazard Reduction Program upon congressional reauthorization of the program. Owing to a lack of designated funding, BFRL has yet to fully address the personnel and resource implications of this important national priority, or to develop a comprehensive working plan for this role.
- The BFRL has been given the leadership role for the Senior Executive Interagency Blast Mitigation Committee (IBMC).
- In the area of chemical and biological contamination of buildings, BFRL has taken the lead through its CONTAM computer program (for analysis of multizone, indoor air quality and ventilation) in evaluating the effectiveness of enhanced filtration and of "Shelter-in-Place," identifying building-specific strategies for chemical, biological, and radiation (CBR) protection. CONTAM is now embedded in the Building Protection Toolkit of the Defense Advanced Research Projects Agency.

The BFRL was very active during the past 2 years, to a large extent because of the extra burdens of major research for the country on the WTC investigations and the application of new and developed procedures for the determination of contaminant spread in buildings. The WTC activities, along with the investigation of the fire at The Station nightclub in Rhode Island, represent the first two official investigations carried out under NCSTA. The excellent manner in which these investigations were carried out is a highlight of this period for BFRL and an example of the ability of this laboratory to marshal expertise, both from in-house and from outside consultants, and to manage such investigations in a fully professional manner. Despite a lack of funding for NCSTA and limited funds for the WTC investigation, BFRL conducted these investigations in a comprehensive and exemplary fashion. During both years of this review, the panel was informed by NIST staff that these obligations had had a serious impact on the other ongoing activities within BFRL, and that there was uncertainty as to how best to prepare for such services to the country in the future without adequate funding.

The quality of the work throughout BFRL is high. As documented in reports provided by the groups within BFRL, the work is published in the top journals in each area and presented at the leading conferences. The researchers are well aware of related work in university and government laboratories and are collaborating with key researchers in the related areas.

Following are selected highlights of BFRL activity over the past 2 years:

- The NIST patented weathering device, Simulated Photodegradation by High Energy Radiant Exposure (the SPHERE), has been used in the Service Life Prediction program of the Polymeric

Materials Group (in the Materials and Construction Research Division) to put laboratory studies on weathering exposure on a sound scientific basis.

- The Building Environment Division (BED) has continued its success in developing and promoting the Building Automation and Control Network (BACnet) standard for building automation system communications. This is an excellent example of how BED can work in an industry and move it forward.
- Much of the research in the Fire Research Division is at the state of the art, comparable in quality to that performed at peer institutions in Canada, the United Kingdom, Sweden, and Japan. In the areas of computational fluid dynamics models for fire research, information systems (library and Web resources), and metrology, NIST is outstanding.
- The airflow modeling algorithms that BED has developed are being implemented in one of the most commonly used building simulation tools. They are also being successfully applied to real-world problems such as building security against CBR threats.
- The Office of Applied Economics is the only organization in the United States focusing on the economic analysis of issues and approaches associated with built facilities to combine both theory and tool development, such as a state-of-the-art multi-attribute model for the economic assessment of fire risk-mitigation strategies.
- There is new success at improving the process for integrating more of the work of BFRL into building codes and standards. The BRFL has organized an in-house committee of key BFRL personnel who recommend how BFRL can best disseminate its work so that it reaches the proper code or standards organizations. Recent examples of BFRL involvement in codes and standards include the proposals derived from the World Trade Center investigation and the proposals for code changes pertaining to the use of elevators as a means of escape during an emergency condition.

In carrying out its mission, BFRL attempts to maintain a balance between its long-term, more fundamentally driven work and its responsiveness to immediate needs. With the increased prominence of its role in national security and the safety of the built environment, the lack of enhanced funding has put a severe strain on many of its more fundamental areas of research. Both personnel and resources have had to be diverted to meet the country's expectations, and there is concern about maintaining state-of-the-art expertise in the long term as well as training for new investigations.

Because of the breadth of activities in BFRL, the following discussion of technical quality and merit, relevance, effectiveness, and resources is often tied to specific comments with respect to the three divisions listed above, as well as to the Office of Applied Economics and the activities related to codes and standards.

TECHNICAL QUALITY AND MERIT

The quality of all of the BFRL divisions is high. The rest of this section focuses on these divisions individually.

There is not another facility like the MCRD Construction Metrology and Automation Group's laser radar (LADAR) calibration facility for the construction industry. The division's Inorganic Materials Group is very well known internationally for its work on modeling of the properties of concrete, most of which is incorporated in the Virtual Cement and Concrete Testing Laboratory (VCCTL) program. In the United States, this is the premier group in concrete research, and it is one of the best in the world.

The technical quality of the MCRD's Polymeric Materials Group is at a very high level relative to industrial and academic laboratories working on coatings and sealants. The enthusiasm and energy of the staff and their high level of commitment merit special praise. The development of a unique facility for laboratory weathering studies (the SPHERE) is an outstanding effort, not equaled anywhere else.

The MCRD Structures Group has highly qualified researchers and technical staff. In particular, the leadership on the WTC investigations is impressive and provides visibility well beyond the Structures Group for BFRL and NIST. In their supervisory role on the WTC investigations, BFRL researchers have significant interaction with the external research community and cutting-edge research and development (R&D) efforts. The excellent leadership by the Structures Group in the WTC investigations has provided a good start for a multihazard systems approach to structural design and has demonstrated good collaboration across BFRL. The WTC work was conducted with state-of-the-art tools and approaches; it goes far beyond any previous studies to combine structural response, impact loads, and fire loading. The real challenge will be to translate lessons learned to the broader challenges of performance-based design for multihazard loadings.

Another BFRL division, the Building Environment Division, has continued to produce high-quality and relevant work. BED has continued its success in developing and promoting the BACnet standard for building automation system communications, providing an excellent example of how BED can work in an industry and move it forward. The technical quality of BED work in computer-integrated building processes is at the leading edge in this field. Through continual participation in key national and international building industry organizations—including Fully Integrated and Automated Technology (FIATECH); the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE); the American Institute of Steel Construction; the International Alliance for Interoperability; and the International Organization for Standardization—the BED maintains a broad knowledge of and strong links with work being done by others in the field.

BED staff manage the FIATECH Automating Equipment information eXchange (AEX) project. The AEX project is developing standards for data exchange between software tools used by the capital facilities industry. Such standards have the potential to greatly improve efficiency and quality in the facility design, construction, and operations life cycle. BED's Computer-Integrated Building Processes Group is finally beginning to deliver products through the FIATECH AEX project, which is increasing the visibility of and industry participation in information-exchange protocols.

The guarded hotplate has been the American Society for Testing and Materials (ASTM) standard test method for measuring heat-transfer properties of materials. The High-Temperature Guarded Hotplate now under fabrication at NIST will extend the range of temperatures under which Standard Reference Materials can be tested. The High-Temperature Guarded Hotplate, under development for a number of years, is nearing completion. It is expected that the investment in technology and instrumentation will be bringing usable research applications very soon.

The airflow modeling algorithms that BED has developed are being implemented in one of the most commonly used building simulation tools. They are also being successfully applied to real-world problems such as building security against CBR threats.

BED testing of residential fuel cells is also innovative, and the technical level of this project is very high. The resulting data provide a wealth of quantitative information that is not available in the open literature. A paper describing the results is being prepared for the American Society of Mechanical Engineers (ASME) *Journal of Fuel Cell Science and Technology*. The BED, a recognized leader in this field, has produced a large number of technical publications. BED personnel are extensively involved in the relevant professional societies (ASHRAE and ASTM) and federal government committees (in the Department of Homeland Security and Environmental Protection Agency) dealing with the issue of CBR protection.

The Heating, Ventilation, Air Conditioning, and Refrigeration (HVAC/R) Group has brought much of its research to closure in recent years. Further evidence of high technical quality is given by the publications in the area of HVAC/R equipment performance—especially the 14 papers from this four-person group in 2004. One of the researchers was awarded the 2004 NIST Best Communication Award for a paper, and a paper by another researcher is being translated for publication by several foreign countries. BED programs demonstrate a balance between addressing immediate needs of customers and carrying out longer-term research.

Much of the research in the Fire Research Division is at the state of the art, comparable in quality to that performed at peer institutions in Canada, the United Kingdom, Sweden, and Japan. In the areas of CFD models, information systems (library and Web resources), and metrology, NIST is outstanding. In most projects the work is complementary to or builds on the state of the art.

The Large Fire Laboratory facilities are very impressive. The FRD has developed the facilities and expertise to respond effectively to many of the fire disasters and issues that compromise fire safety in order to increase personal and national safety and security. In a few areas, FRD is engaged in capability building to reach the level that exists elsewhere. In these cases there needs to be special attention paid to making full use of knowledge and capabilities developed elsewhere.

The WTC investigation and, to a lesser extent, the investigation of the nightclub fire at The Station in West Warwick, Rhode Island, have energized FRD. The enthusiasm of those reporting to the panel on their research was palpable, and the excitement of seeing FRD's contributions receive recognition within NIST and nationally has stimulated all members of the division. The response to the WTC event has helped strengthen the integration of efforts within the division and also has also strengthened ties between FRD and the other divisions within BFRL. An impressive product of this collaboration is the coupling of the Fire Dynamics Simulator (FDS) with heat-transfer and structural codes and the verification of the predictions of the coupled FDS and heat-transfer models in tests conducted at the Large Fire Laboratory.

The Office of Applied Economics, a distinct office with a dedicated staff within BFRL, provides 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. The focus of OAE's research and technical assistance is microeconomic analysis. The OAE provides information to decision makers in the public and private sectors who are faced with choices among new technologies and policies relating to manufacturing, industrial processes, the environment, energy conservation, construction, facility maintenance, law enforcement, and safety. It also develops and conducts prototype training programs in applied economics for scientists and engineers. The Office of Applied Economics continues to display very high technical quality of research. The OAE is involved in the application and development of state-of-the-art technologies, particularly for implementation and dissemination. New theoretical approaches are being developed.

The integration of BFRL efforts in the areas involving codes and standards into the activities of its divisions has demonstrated significant advancements from past years. The Board is very encouraged by and pleased with the work being carried out under the new director—the codes and standards work is considered exemplary and is to be applauded.

RELEVANCE

The Structures Group of MCRD is engaged in numerous very relevant programs, but the level of effort and commitment of resources to the WTC study are dominant, and more attention needs to be paid to other relevant applications. Many of these efforts should be addressed in parallel rather than sequentially with the WTC investigations. The efforts of the National Earthquake Hazard Reduction Program, National Construction Safety Team, and Interagency Blast Mitigation Committee are extremely relevant activities. However, to date they are largely approached as separate and independent activities, an approach that does not take advantage of the opportunities for work on multihazard problems.

The mission focus of the Construction Metrology and Automation Group is excellent; it is squarely focused on the key NIST mission of delivering measurement and standards capabilities. All projects contribute to the development of standardized tests, new methods, or new data.

The activities of the Inorganic Materials Group clearly support high-priority national needs. There is a clear, though mostly coincidental, tie to NIST Strategic Focus Areas and objectives.

The problem of coatings durability is very large and complex, and it is obvious that not all of it can be addressed by the Polymeric Materials Group. The current programs address an appropriate and important subset of the overall problem. Current plans to extend the work to include pigment contributions are appropriate and appear to be suitably supported. This group's Service Life Prediction program has the potential to change industry practice in the evaluation of coatings durability. Broader applications of the methodology should enable similar improvements in the evaluation of sealants and other polymeric materials.

The Board has some general concerns related to the role of the Building Environment Division in NIST's Strategic Focus Areas and to BED's long-term goals and future directions. The BED should highlight its role in furthering NIST's Strategic Focus Areas and should apply concerted effort in these areas. The relevance of BED is quite evident to the Board, but may not be as evident to all those having an interest in NIST. For example, BED's vision and effectiveness in developing technologies for information management for buildings should be recognized. The leadership role and effectiveness of the division in making the BACnet standard into an industry standard is evident. The BED has a similar leadership role in an even broader information management activity related to the Computer-Integrated Building Processes Group, which should become a flagship activity for BED and BFRL.

The BED enjoys a clear leadership role in the national program entitled Healthy Buildings, as evidenced by the division's activities on key industry committees and the tools that BED has developed that are making inroads in the industry. While Healthy Buildings is not explicitly included in the NIST Strategic Focus Area of Biosciences and Healthcare, it should be: BFRL leadership should actively advocate for including this area of activity in the definition of this Strategic Focus Area.

The BED also can be a leader in another area, which has not been defined as a NIST Strategic Focus Area but that is certainly a clear focus area within industry, namely, sustainable buildings. The exponential growth of the U.S. Green Buildings Council is one clear indicator of industry's interest in sustainable buildings. Other organizations, such as ASHRAE, are making sustainable buildings one of their high-priority strategic areas. One of the problems with sustainable buildings as an area of focus is that there are no clear definitions in the industry. NIST will always have an important role in standardizing definitions, and it should have a pivotal role in standardizing definitions for sustainable buildings.

The BED has become an industry leader in many areas, but a number of its activities appear to be a collection of tangentially related projects. At present there is a large number of projects in a wide range of activities in BED, and several appear to be short term rather than long term. It may be helpful for the division to assess whether all of these projects fit into its vision.

The formal confirmation by NIST and BFRL of the importance of codes and standards through inclusion of this area as a research area (Fire Standards, Codes, and Testing) is a significant and vital development for FRD that will focus the dissemination of division products. This emerging recognition at NIST and BFRL that participation in codes and standards is a major means by which FRD can impact the efficiency and safety of our built environment, consumer products, and first responders is to be commended.

The research area called Reduced Risk of Fire Spread has recently been expanded from that of Flashover to Fire Spread, addressing a problem with focus of the previous program. As a result, the potential impact of the program has not been realized, an issue that needs to be addressed. The program Fundamental Fire Science has replaced the former program Advanced Measurement and Prediction Methods; an issue needing attention is that while the Fire Dynamics Simulator appears prominently in the program's approach statement, the actual FDS project work in the program is modest. The Fundamental Fire Science Program includes projects that study heat release rate in large-scale fire measurements, use of total heat flux gauges, gas velocity measurements in the Large Fire Laboratory, new measurement of soot volume fraction in fires, fire growth and spread on real objects, predictive methods, visibility limits in smoky environments, and assessment of the universality of cone calorimeter experimental data to subgrid fire growth and spread models. The panel recognizes the value of fundamental research on fire, while at the same time concluding that the projects within the Fundamental Fire Science Program should be more systematically oriented toward producing more outcomes of importance to FRD's clients.

While calibration activities have been active in the past year, the use of the Large Fire Laboratory for project work has been limited, and new meaningful projects should be developed. Most work at the Large Fire Laboratory is on other agencies (OA) projects and not for Scientific and Technical Research and Services (STRS) research. This means that the use of the laboratory is sporadic and the outcome is opportunistic.

The OAE in BFRL provides unique measurement and standards activities. The OAE has several activities relating to homeland security and, more broadly, to natural and intentional risks. Several of these activities are in collaboration with the Structures Group. The OAE often convenes groupings of industry and customer representatives to identify critical issues, identify and/or review relevant data, assess theoretical and analytical development, and provide feedback on tool development. The OAE responds in both a timely and an effective manner in its research program, and it identifies and meets its milestones.

The following challenges relating to the future relevance of its efforts face the Building and Fire Research Laboratory:

- The planning and construction of a National Structural Fire Testing Laboratory.
- Planning on what it means to be the designated lead agency for the National Earthquake Hazard Reduction Program: How will NIST's lead differ from that of the Federal Emergency Management Agency in the past?
- Identifying the role that NIST/BFRL will have as they work with the Department of Homeland Security on the protection of critical infrastructure against terrorist attacks.
- Determining whether there is a role for NIST/BFRL in the multihazard performance assessment of buildings.
- Determining how the NIST Strategic Focus Areas are reflected in the BFRL vision and strategic plan.

EFFECTIVENESS

As evidenced by the lists of outreach activities that BFRL provided for this assessment, project results are effectively communicated to the technical community and to relevant government agencies, for example, through widely read and well-received reports and through conference and journal publications. Especially important for the work of the past 2 years is that the WTC investigations are expected to be broadly disseminated. Representatives of all of the BFRL divisions have been invited to give keynote lectures at major conferences and in other ways are successful at making their work generally available to customers. A clearly articulated outreach initiative defining the distribution frequency and methodology of outreach would be helpful to enhance the current practice of all BFRL divisions.

Over time all divisions should consider whether they are enabling future "success stories." The level of funding needs to be better aligned with projects that have the potential for significant impact. All divisions should continue their tradition of long-term vision and investing in basic research and development to ensure that there are industry-relevant tools to meet future industry needs.

Some of the work areas of MCRD, such as progressive collapse, could benefit from better and earlier dissemination of best-practice documents. Some projects of this division are not yet far enough along to assess their impact.

The CONTAM program of BED has been used to evaluate the effectiveness of enhanced filtration, to provide guidance on retrofitting buildings for security, to evaluate the performance of Shelter-in-Place, and to identify building-specific strategies for CBR protection. In the areas of diagnostics and commissioning, BED is playing a key role through its leadership in internationally coordinated research and development with the International Energy Agency. The BFRL has invested effort to take this technology from basic research all the way through to agreements with manufacturers that are coming very close to commercialization. As indicated above, BED is beginning to deliver information management products through the FIATECH AEX project, which is increasing the visibility of and industry participation in information exchange protocols. This area of technology appears to be reaching a tipping point at which it has the potential to become a more important driver in the industry. Many of the BED computer programs are available for free downloading from the NIST Web site, and the others are available by purchase from NIST. There is good documentation for customer feedback on use of the programs. The investment in BACnet development quite a few years ago has led to industry leadership. The BED investment in basic research and algorithm development in the area of building airflow has borne fruit in the form of industry-accepted simulation tools and tools that have solved real-world problems.

The FRD continues to provide a national resource for evaluating equipment for fire loss reduction and providing the assessments needed to establish standards. These activities are particularly effective because FRD personnel are well connected to the fire service community and are members of many of the relevant standards committees. FRD products can be directly implemented to the various stakeholders of BFRL. In many cases, these products have an immediate impact on direct and indirect fire-related cost, improving life safety and economic competitiveness, and they facilitate regulatory revisions. The current outreach offering products and materials to the firefighting community is good, as evidenced by attendance and presentations of FRD personnel at several related trade shows, by the Fire.gov initiative, and by the distribution during the past year of FRD results as Web-accessible reports and compact disks (CDs).

The technical productivity within FRD as measured by peer-reviewed publications is modest. The staff averages about one peer-reviewed publication per professional staff member annually, but the trend is downward. Links are maintained between FRD researchers and the external community, though opportunities for interchange are less than had been available historically. Direct interchanges between staff and national laboratories worldwide have diminished over time. It is noted that some staff members still manage to participate in international fire research organizations and meetings.

An issue noted within FRD is that the research should be more results-oriented. The projects should have clearly identified outcomes with clear measures of success for clients and should be benchmarked against the work of peer organizations. The value and function of the technical programs need to evolve to be more responsive to division goals. The former FRD research program, the WTC R&D Program, has been renamed the Safety of Threatened Buildings Program. Projects within this program—Method of Fire Resistance Determination, Occupant Behavior and Egress, Emergency Use of Elevators, and Firefighter Lifts—have been its areas of research for 3 years, yet little in the way of meaningful research results has come from these efforts.

Several significant efforts within FRD were made in the WTC investigations. The impact of the WTC on the laboratory's research is far in excess of the $16 million formal cost of the investigation, and the investigation is extending beyond the original schedule. This has required ongoing focus by researchers and has seriously limited their productivity as researchers on other projects. As a result, the costs of the investigation have far exceeded the monetary cost. Since this is the first investigation performed under the National Construction Safety Team Act of 2002, it involved a steep learning process. Lessons learned from this investigation should reinforce the need to ensure that funding is available for the National Construction Safety Team and that a team is in place and prepared for the next national fire disaster.

The OAE is extremely effective at employing multiple techniques to disseminate its results. All analytical tools are incorporated into software applications, applets, or Web pages. All software can be downloaded free of charge from the Web page. Most projects include training materials and/or courses to teach the analytical techniques. OAE techniques and tools have had a demonstrable long-term impact. There is strong representation by OAE personnel in technical papers and invited talks at major conferences.

The current work in codes and standards is the most positive and encouraging that has been seen in the several years. There is a fresh approach to the idea of integrating the work of BFRL into the building codes and standards. Much of this new invigoration springs from the research that has gone into the WTC events of 2001. However, the BFRL Director should be given credit for recognizing the value of BFRL's participation in this arena. To aid in this integration, the Director has asked one of the division heads to organize an in-house committee of key BFRL personnel who will meet periodically, review what the laboratory is working on, and then analyze and make recommendations on how BFRL can best disseminate its work so that it reaches the proper code or standards organization.

RESOURCES

Overall, groups within BFRL are for the most part just at adequate levels of human resources. As discussed below, however, there are several areas within the laboratory that are subcritical either for the tasks at hand or for those expected by the country to be needed in the future.

There does not appear to be sufficient staff to properly cover all areas for the large number of projects in the Structures Group in MCRD. A serious staffing review and human resource development plan needs to be put in place to ensure that BFRL and the Structures Group can carry out their mission—not just now but 5 years from now.

Given its small size, the Construction Metrology and Automation Group is doing very well; the group's focus has improved, moving toward more scientific and fundamental work (still cognizant of applications). The plans for a construction automation testbed are exciting, but there do not appear to be the resources (staffing, facilities) in place to set up such a facility properly. The available tools are excellent and state of the art. The facilities are adequate, but unfortunately they are spread out across the NIST campus, which fragments the small group too much.

The available scientific and technical competencies in the Inorganic Materials Group are adequate to achieve success. The staff seems to be satisfied with the equipment and facilities. However, it is surprising that there are no central facilities for expensive tools such as the scanning electron microscope, transmission electron microscope, nuclear magnetic resonance, and X-ray photoelectron spectroscope (XPS). These tools provide the ability to make high-resolution measurements at the nanoscale. Currently, researchers need to share equipment, which can result in a misuse of the time of experts in providing services to colleagues.

The Polymeric Materials Group is well staffed for current projects, but future changes in direction may require changes in personnel assignments. While additional technician support would be desirable to facilitate the experimental work, this does not appear to be an urgent need. The addition of further analytical capability (notably a dedicated XPS) would be desirable.

The BED should have a goal for long-term growth and a plan for achieving it. While the division has effectively leveraged labor categories such as contractors, students, and visiting scientists, long-term sustainable growth requires the acquisition of more permanent staff. This cannot be done without adequate Scientific and Technical Research and Services funding. The division should find a comfortable balance between STRS and OA funding; it currently believes that it is not receiving sufficient STRS funding. The BED is effective at securing OA funding, which shows a very healthy relationship with industry and relevance, but it may not be sufficient to grow the division to fulfill future missions. The Computer-Integrated Building Processes Group is limited in its impact on long-term transformation of industry processes owing largely to funding and human resource constraints. In addition to a lack of funding and staffing, BED overall suffers from a lack of information on funding and a lack of stability in funding, both of which are needed for effective long-term planning.

Several of the current FRD programs may result in significant impact on society as a whole or on individual segments of society (individual stakeholder groups). However, if FRD is to move collectively to the next level of performance, there need to be clearly stated product goals. These goals need to be supported with specific performance objectives and time lines. On many FRD products, work can go on for years with little or no definition of product goals and no measurable outcomes.

The level of support for FRD projects from other agencies and industry is lower than it has been in the past. Research on thermal imagers and mattress fires, the development of models for the U.S. Forest Service on the ignition of structures at the wild-land–urban interface, and the development of high-throughput screening of fire-resistant materials are good examples of industry projects that have been completed or are under way. While the WTC investigation and the contraction of domestic expenditures have undoubtedly had an impact on OA funding, the opportunity exists to increase this funding base through effective stakeholder outreach. The level of effort is adequate to complete the project objective in many cases, but in work for other agencies, additional resources for more complete data acquisition and comprehensive analysis would have yielded results to benefit the larger community as well as the customer. This would represent a good use of STRS funding.

The OAE has lost two positions (three people at the time of this writing) due to retirement, leave, or departure. Several significant opportunities, particularly a few projects associated with homeland security, will require additional resources. Available tools are adequate. The OAE needs to expand its technical competencies, particularly in human resources, to respond effectively to emerging requirements.

With the WTC analysis, the Rhode Island nightclub fire report, and the creation of a National Construction Safety Team, NIST and BFRL are poised to assume a prominent role in this arena in the future. To do so, they must leverage the expertise gained during the past 18 months and incorporate it into a vision of their future. This must include the acquisition of state-of-the-art equipment for conducting structural analyses and the integration of the expertise of the various laboratories toward the fulfillment of the vision.

The tragic events of the WTC attacks showed the importance of the resources of BFRL. The expertise of experienced personnel and specialized test facilities are critical national resources. The need for such resources that can be utilized during disasters has been recognized by the formation of the National Construction Safety Team, but without funding for this initiative it may be difficult to maintain the resources at the level needed to address future crises. The resources for the WTC and the Rhode Island nightclub fire investigations were made available by transferring personnel from other programs, reducing the effectiveness of those programs. Without funding for the National Construction Safety Team, future emergencies will require similar sacrifices or more extensive use of contractors to do the research.

3

Chemical Science and Technology Laboratory

INTRODUCTION

The Chemical Science and Technology Laboratory (CSTL) is the U.S. reference laboratory for chemical measurements. It is entrusted with developing, maintaining, advancing, and enabling the chemical measurement system for the nation, thereby enhancing U.S. industry's productivity and competitiveness, assuring equity in trade, and improving public health, safety, and environmental quality.

The laboratory staff is organized in five divisions, as shown in Appendix A:

- Biotechnology Division (BD),
- Process Measurements Division (PMD),
- Surface and Microanalysis Science Division (SMSD),
- Physical and Chemical Properties Division (PCPD), and
- Analytical Chemistry Division (ACD).

Appendix A also presents the staffing trends for the laboratory (see Figure A.3).

MAJOR OBSERVATIONS

The CSTL is engaged in a large number of chemical science and chemical technology research and metrology activities that are closely interrelated, highly effective, and clearly focused on the metrology needs of the nation. The Board reviewed a large fraction of the work under way in the laboratory and commends the technical staff and management for achieving an extremely high level of consistent quality, effectiveness, and productivity across such a broad range of activities. The CSTL remains vibrant and essential to NIST's mission.

This section highlights a number of activities that are exemplary in nature and also identifies several opportunities for improvement. Programs and projects reviewed by the Board during the past 2 years but not explicitly discussed in this chapter have been deemed by the Board to be "on track"; they are fulfilling their missions, are achieving their objectives, and are generally considered to be excellent.

The CSTL is truly a national resource, conducting outstanding research to support the continued development of a wide range of measurement capabilities, providing critical and reliable chemical and physical properties data and essential reference standards. Its work spans the entire scientific spectrum, from fundamental physics through chemistry and into biology, and supports an astonishingly diverse group of industries. The quality of the scientific staff is superb, and the laboratory has undergone a rather dramatic transformation over the past decade or so to become entrepreneurial and customer-focused while being mindful to maintain and advance its core competencies. Evidence of its high technical quality, relevance, and effectiveness, some of which is presented in this report, is abundant.

CSTL's work has been increasingly organized along programmatic lines in order to encourage and require collaboration and cooperation among divisions and between laboratories. These strategic directions include nanometrology, biometrology, properties information infrastructure, process metrology, and chemical metrology, which are all well aligned with NIST's Strategic Focus Areas. Adopting this matrix management approach has enabled the laboratory to tackle important problems that are inherently interdisciplinary by assembling teams with the appropriate backgrounds and expertise. A few outstanding examples of both intra- and interlaboratory collaborations include the following: the Tissue Engineering Competence Program, a collaboration between the Biotechnology Division of CSTL and the Polymers Division of the Materials Science and Engineering Laboratory (MSEL); extensive collaborations between the Physical and Chemical Properties Division and the Analytical Chemistry Division on new biological (including weapons) and health-related applications of mass spectrometry in support of missions of the National Institutes of Health (NIH) and Department of Homeland Security (DHS); and Johnson Noise Thermometry, a collaboration between the Process Measurements Division and the Electronics and Electrical Engineering Laboratory.

Significant accomplishments include the following:

- Moving several divisions to the Advanced Measurement Laboratory (AML) has ensured that CSTL will maintain its extremely high technical quality in many areas, allowed it to close the gap in other areas, greatly enhanced its capabilities, and allowed it to move in new directions, thus enhancing its position and value to the nation. Instrumentation that barely met specifications in their old locations (despite years of tuning) immediately exceeded expectations owing to the superior environmental control in the AML. The addition of the next-generation analytical electron microscope, with sub-Å spatial resolution, in early 2006 to the existing suite of analytical instrumentation already installed will make the AML a leading facility in the world for nanometrology.
- CSTL's expanded efforts at the Hollings Marine Laboratory (HML) in South Carolina are outstanding. The existing and proposed new projects are truly synergistic, applying CSTL's expertise to areas of interest to the other HML partners and thus leveraging the investments of all parties. The excitement and enthusiasm of the HML staff are palpable. The interactions at the HML represent an exemplary model of scientific collaboration among a number of federal and state agencies.
- The CSTL has appropriately adopted the International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) Standard 17025, General Requirements for the Competence of Testing and Calibration Laboratories. This new quality program has been adopted by all measurement service groups, which has resulted in an increased emphasis on documentation and formal validation before new or improved measurement services are offered.
- ThermoML is a powerful new approach, developed by the Thermodynamics Research Center (TRC), for the acquisition, evaluation, storage, and dissemination of thermophysical and thermochemi-

cal reference data. It is currently being balloted by the International Union for Pure and Applied Chemistry for acceptance as an international standard and is now being used voluntarily by five scientific thermodynamics journals, leading simulation software companies, and data repositories around the world as the accepted format for the exchange of these data. This product is a fine example of CSTL's forward-looking approach to research and development (R&D) that results in a resource of great value.

Opportunities for improvement include the following:

- Unless increased, the budget is likely to affect the laboratory's ability to maintain the knowledge base and expertise of its highly experienced staff, its ability to attract new staff in order to replace losses in existing areas, and its ability to initiate new activities that are needed to support the nation's measurement and metrology needs of the future.
- The fact that NIST is no longer part of the consortium that manages the Protein Data Bank is cause for concern. While there is some merit to the argument that competitive renewal proposals might result in enhanced performance, NIST should continue to be a partner in this enterprise for two reasons. First, the collection and dissemination of the physical and chemical properties of molecules (in this case biomolecules) is clearly a central part of NIST's mission; second, this collection of data is so critically important to the nation that it should reside permanently in a federal laboratory.
- Despite repeated recommendations and encouragement from the Board over a number of years, little progress has been made in defining goals for the Biotechnology Division and in implementing strategies to achieve those goals. The Board has consistently agreed that this is a vital area to which CSTL can and should make significant contributions, that CSTL cannot possibly contribute to all fields of this exploding area of science and technology, and that CSTL should select a few areas that are consistent with its mission and focus on those areas where its efforts will make a difference. The new CSTL Director has been developing a new strategy for dealing with the biological sciences within the laboratory that may include reorganizing the Biotechnology Division along disciplinary lines (like the other four CSTL divisions) and looking at biosciences more broadly as an activity that spans all of the divisions of the laboratory. The Board endorses this approach.
- The CSTL/Center for Advanced Research in Biotechnology (CARB) interaction has not been particularly effective; the laboratory should vigorously pursue new ways to increase collaboration and cooperation with this potentially valuable asset. Efforts should be focused on the development of areas in which NIST's expertise can contribute to problems of interest to CARB scientists, resulting in synergistic interactions. The Hollings Marine Laboratory is an outstanding example of this kind of collaboration, and CSTL should consider using it as a model for the development of stronger ties to CARB.

TECHNICAL QUALITY AND MERIT

Overall, the quality of the technical work done in the Biotechnology Division is very high and in most cases outstanding. The work reviewed is highly effective and relevant, driven by a clear strategy, with stakeholders identified and often participating in the application of the technology or measurement techniques as soon as they are developed. However, the breadth of the technology and the rate of change in the biosciences area are clearly challenging the division to maintain its position in the life sciences and associated biotechnology. Unless additional resources are made available, the division will not be able to meet the rapidly growing and changing needs of the nation in this area for research, standards, and metrology.

The Biotechnology Division has played and should continue to play a pivotal role in NIST's effort to address critical measurement and data needs for the rapidly developing biotechnology industry. The division remains a vital resource to NIST and to CSTL, serving as a key link to the biotechnology industry, and it is critical to NIST's global presence in the rapidly evolving biotechnology field and to strengthening the position of the United States in the global economy.

The Biotechnology Division manifests the NIST part of the joint institute with the University of Maryland Biotechnology Institute's Center for Advanced Research in Biotechnology. The division's involvement with CARB has been important to the quality and relevance of the division's research programs; strengthening its ties with CARB and CARBII is deemed critical to CSTL's continuing development of the highest-quality metrology-based research and standards activities. The Structural Biology Group's programs (most in collaboration with CARB) are judged to be outstanding. Anticipated areas of expansion include Good Manufacturing Practices bioprocessing, plant and insect transformations, high- and medium-resolution structural biology, microarray/gene expression, and protein production/characterization.

The Board regrets NIST's elimination from the consortium that manages the Protein Data Bank (PDB), which is the single worldwide repository for the acquisition, evaluation, and dissemination of three-dimensional protein and nucleic acid structural data. The Biotechnology Division of CSTL played a significant role in developing the current PDB, and the Board encourages CSTL (and NIST) to find a way to reengage in this effort.

The Process Measurements Division has undergone a significant restructuring and project/mission refocusing, with a number of activities relocating to the new, state-of-the-art AML. All of this has been beneficial to the group, which is newly energized and well focused on clearly defined objectives.

The division's strategy of continuous improvement of its capabilities by continuing research on traditional measurement parameters provides the basis for it to maintain preeminence among National Metrology Institutes (NMIs) in most parameters for which it provides measurement services. As one of many specific examples, the division's Thermometry Group is the world leader in this key measurement parameter, as judged by range, uncertainty, and participation in international technical activities. This integration of research and standards maintenance is a model that should be considered for application to other standards activities across NIST.

PMD's humidity generation and measurement capability appears well on the way to matching or exceeding other NMI capabilities over all ranges and to providing calibration to customers with faster, more automated services. Its trace humidity measurements are already unsurpassed worldwide and show promise for additional improvement in both range and uncertainty.

The division does not have high-flow-rate natural gas measurement capabilities that are equivalent to the best NMIs in the world; this deficiency is potentially detrimental to the nation's commercial competitiveness in this area by not having NIST-traceable metering standards. The division is addressing this issue, however, by developing relationships with two companies that do have outstanding high-flow-rate test and calibration stands. This collaboration should allow the division to improve capabilities and to reduce uncertainties and thus to match or exceed those of the best European NMIs quickly and at reduced cost.

Improvements in flow, temperature, pressure, and other basic measurement parameters have obvious and direct impact in commerce and industry. As the division's research projects enable more measurement standards to be based on "intrinsic" principles rather than on physical artifacts, significant improvements in performance and accuracy can be expected to spread steadily throughout the U.S. measurement system. Examples of current projects to develop standards of this type include Johnson Noise Thermometry, Gas Concentration Standards Based on Cavity Ring-Down Spectroscopy, and the Atomic Standard of Pressure.

The division has achieved significant reductions in measurement uncertainty for flow-measurement projects of water, atmospheric gases, and hydrocarbons. NIST gas-flow-rate uncertainty was reduced by an order of magnitude in the 0.1 to 2000 standard liters per minute (slm) range and is now the best in the world. Hydrocarbon-flow-rate uncertainty in the range of interest to the Department of Defense (DOD) has also been reduced by an order of magnitude, and for higher-rate gas flows (to 78,000 slm), the uncertainty has been cut in half. In response to a constant push for improved flow-rate measurements from the DOD, these projects bring the U.S. capability in these ranges in line with those of the best NMIs.

The Surface and Microanalysis Science Division is responsible for the characterization of the spatial and temporal distribution of chemical species, with a particular focus on microanalysis, surfaces and interface analysis, and advanced isotope measurement techniques. The overall quality of the personnel in this organization is very impressive. Two NIST fellows, in particular, are both luminaries in the areas of X-ray microanalysis and Auger and X-ray photoelectron spectroscopies, and the Board hopes that plans are in place to continue their essential work in the event of possible upcoming retirements. Recent work on developing the silicon drift detector approach is remarkable; it will take the technique to the point where it will assuredly achieve great industrial importance.

Multidimensional (hypercube) data storage using a newly developed extensible markup language (XML) format has been further developed and is being adopted in many other areas of the laboratory. High-level international adoption of this approach is likely to result in an increased richness and depth of analysis of complex analytical systems. The division followed the Board's recommendation in the previous report: the characterization of SiGe films has been completed, and resources have been moved on to other activities. The nascent effort in super-resolution spectroscopy (a new NIST competence project) is extremely promising. It will provide an entirely new way to characterize materials on the sub-100 nm length scale, a challenge of immense current interest, importance, and relevance to a number of areas of science and technology.

The Physical and Chemical Properties Division is responsible for providing measurements, standards, data, and models for the following: the thermochemical, thermophysical, and interfacial properties of gases, liquids, and solids, both as pure materials and as mixtures; the rates and mechanisms of chemical reactions in the gas and liquid phases and at surfaces; and fluid-based physical processes and systems, including separations and low-temperature refrigeration, heat transfer, and flow.

Many capabilities of the PCPD are unique when compared with the state of the art in physical and chemical properties science. A few examples are summarized below:

- *Unique fluid properties experimental apparatus.* Several capabilities in the Experimental Properties of Fluids Group, including heat-capacity, isochoric PVT (pressure, volume, temperature), viscosity, and automated thermal conductivity apparatus, have become the only working examples in the world. Maintaining these capabilities is important because experimental work continues to be deemphasized throughout the thermodynamics community elsewhere.
- *Mass spectral database.* This database is supplied under license from NIST on over half of the world's commercial mass spectrometers. NIST is responsible for gathering, authenticating, updating, and archiving the data. A new release is planned for 2005 in which 20,000 new compounds, spectra for more than 2,000 compounds, and, for the first time, gas chromatography retention index data for 19,000 compounds will be added.
- *State-of-the-art Helmholtz energy reference equation of state (EOS).* A recently developed "short-form" version of the reference fluid EOS can be used to describe all of the thermodynamic properties for fluids with limited data sets but with higher accuracies (typically 0.1 to 0.5 percent in density, 1 to 3 percent in liquid heat capacities and sound speeds) than previously attained for these fluids.

- *ThermoML.* Developed over several years by the Thermodynamics Research Center, this XML-based approach for the storage and exchange of thermophysical and thermochemical property data has been accepted by the International Union for Pure and Applied Chemistry and is now being voluntarily used by five scientific thermodynamics journals. The TRC also provides a unique database of critically evaluated experimental data.
- *Primary standard dual sinker densimeter.* This apparatus is used to provide data for accurate equations of state (most recently for propane) and density standards over a wide range of temperatures and pressures for NIST reference materials (e.g., work on toluene is in progress). An exploratory project to investigate the feasibility of the densimeter for use as a primary temperature standard showed that a similar apparatus with larger sinker volumes would be required.
- *Computational Chemistry Comparison and Benchmark Database (CCCBDB).* This database, developed by the Computational Chemistry Group, provides benchmark data for evaluating theoretical methods and for assigning uncertainties to quantum chemical computations, particularly thermochemistry. The Web site, which contains tutorials and graphical user interfaces, receives an average of 25,000 visits per month.
- *Microfluidic critical point apparatus.* This new apparatus consists of a high-performance liquid chromatograph capillary (300 μm diameter, 20 mm long) that can be rapidly heated to produce critical opalescence, which yields measurement of the critical temperature and pressure as well as information on heat flow in near-critical fluids. This is a project in the division's ongoing initiative on small-sample, high-throughput thermophysical properties measurements.
- *Cryogenic flow calibration apparatus.* This facility, unique in the United States, has been used to calibrate liquid nitrogen flowmeters for more than 40 years. NIST provides a vital service with this facility. However, since the flowmeter companies use the NIST-calibrated meters as reference standards to calibrate the meters that they sell, the demand is relatively small (15 to 20 meters calibrated annually).
- *Increased staffing in Computational Chemistry Group.* The division has increased its investment in the Computational Chemistry Group (partially through personnel realignments), resulting in an increase in staffing from four staff members 7 years ago to nine staff members currently and almost an equal number of full-time, postdoctoral guest researchers. This investment has produced a lively and dynamic group whose work is synergistic with that of the experimentalists in the division, greatly adding value to their outputs. The Computational Chemistry Group is also aggressively developing new methodologies in quantum chemistry and molecular modeling to support NIST-wide efforts to understand complex systems. The group has demonstrated sophistication as well as the wisdom it has shown in selecting problems for their distinctiveness and relevance.

The Analytical Chemistry Division maintains outstanding metrology based on core competencies in the following: 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 generally cover all those of importance in the analytical sciences.

In 2005 the Organic Analytical Methods Group (OAMG) placed an emphasis on dietary supplement Standard Reference Materials (SRMs) (through the National Institutes of Health [NIH]), marine health and bioscience applications (through the Hollings Marine Laboratory), forensic and homeland security measurements and standards, clinical standards, and protein quantification. These are among the more important analytical applications facing society today. OAMG's work represents superior productivity while maintaining high quality, providing advanced metrology work in its key activity areas. An important methods development project was the determination of brominated flame retardants in the environment. The research showed that these materials, which can compete with thyroid hormones and act as endocrine-function disrupters, are ubiquitous in the environment and may have serious health ramifications if left unchecked.

Another new OAMG project responded to a request by the Department of Justice (through the NIST Office of Law Enforcement Standards) regarding the standardization and uses of pepper spray canisters, for which there are no standard formulations or efficacy measurements. The project will define the pepper extract compositions of different suppliers and the propellant systems used. These are particularly fine examples not only of the technical excellence of CSTL's work but also of its agility and responsiveness to requests from other agencies.

The molecular spectroscopy work has focused on standards for fluorescence, near-infrared, Raman, and ultraviolet-visible spectroscopies. There has been a conscious effort to transfer the solid-material, optical SRM production to secondary sources of supply, following development and characterization by the CSTL staff. The Analytical Chemistry Division should develop a plan for the seamless continuation of optical SRM production; this capability is being lost within NIST, since one of the few staff members in this area retired in 2004. The optical imaging community needs optical standards for microarray and imaging methods that focus on spatial resolution, absorbance or intensity, and spectral line shape; homogeneity standards for comparison of optical images would also be of acute interest. This technical area requires renewed invigoration and expansion to meet current and projected consumer demands. The division does not currently have any specialized imaging technology expertise, whereas aspects of spatial imaging, and particularly image processing, are highly developed within other divisions of CSTL, particularly in the Surface and Microanalysis Science Division. The CSTL should encourage collaborations between these divisions to assist the Analytical Chemistry Division in developing new competencies to support the particular needs of its customers.

The potential of the Nuclear Methods Group and the Gas Metrology and Classical Methods Group has been unrealized owing to operational structural issues. The Board saw little evidence of innovation or new project proposals that address emerging needs, and some group leaders were not prepared to make recommendations that would address some impending difficulties. An overall strategy for the prioritization of activities was not apparent to the Board. These two groups continue to operate using a model by which very good science is done and high-quality products are delivered, but without the crosscutting, interdisciplinary activities that have been developed in the other groups. A serious infusion of new talent is required to set new priorities and operation paradigms.

As technical relevance and high commercial importance increasingly drive the work of Chemical Science and Technology Laboratory, ACD and CSTL management should consider realignment of the division's present group structure to better reflect areas of technical synergism and customer service operations.

Finally, both the Analytical Chemistry Division and the Process Measurements Division could provide great service to the pharmaceutical industry by engaging in the process analytical technology (PAT) activities now being spearheaded by the Food and Drug Administration (FDA). The need for automation in calibrating analytical instrumentation will require the development of optical and chemical standards, algorithm standard practices, and standard database models for testing algorithms and real-time calibrations. These demanding applications will require the metrology excellence of NIST to be successful in order to achieve the pharmaceutical industry's ambitious goal of 100 percent monitoring. Several groups would welcome NIST's involvement; these include the American Society for Testing and Materials' International Main Committees E13 on Molecular Spectroscopy and Chromatography and E55 on PAT, the United States Pharmacopoeia, and the FDA.

RELEVANCE AND EFFECTIVENESS

The Chemical Science and Technology Laboratory provided the Board with a number of measures of output and impact that are included here. Table 3.1 summarizes some of the CSTL outputs and interactions demonstrating the high level of activity of the laboratory.

In addition to documenting output, CSTL has attempted to measure impact. It has done so in part by commissioning a number of formal economic impact analyses by outside experts (e.g., RTI International) over the past 8 years. These reports are very detailed, and the methodology is thoroughly discussed. In these analyses, selected programs were evaluated both to quantify their impact and to guide CSTL's strategic planning. They included Standards for Calcium Testing (Gallaher et al., 2004); NIST-Traceable Reference Material Gas-Mixture Standards (Gallaher et al., 2002); Cholesterol Standards (Leech and Belmont, 2000); Standards for Sulfur in Fossil Fuels (Martin et al., 2000); Alternative Refrigerants (Shedlick et al., 1998); and Thermocouple Standards (Marx et al., 1997). Benefit-to-cost ratios varied from 3:1 to more than 100:1 across these programs, with social rates of return being generally much higher.

Another example of impact was provided in a letter to then-NIST Director Arden Bement, dated December 22, 2004, from Margo Oge, director of the Environmental Protection Agency's Office of Transportation and Air Quality. She stated that "the development of [diesel fuel] SRMs directly supports the introduction of ultra-low-level diesel fuel with the implementation of the U.S. EPA 2007 highway heavy-duty and 2010 Tier 4 non-road diesel regulations. These regulations when fully implemented, will provide roughly $150 billion annually in health and welfare benefits to the American Public."

The selected examples cited above help demonstrate the economic value of CSTL to the nation. CSTL management has effectively documented these contributions and used these tools to guide its planning. The following discussion addresses selected examples of CSTL relevance and effectiveness.

In the Biotechnology Division, the DNA Technologies Group continues to produce highly visible work with programmatic relevance, with many of its programs effectively reaching its customers in industry and in the scientific community. The program of advanced mass spectrometry of modified DNA bases provides a vital link between NIST and NIH and the National Institute on Aging. The work of this group for the Early Detection Research Network of the National Cancer Institute is outstanding and has been renewed. The program in human mitochondrial DNA for forensic applications and disease diagnosis which is directed at near-term needs of the nation, is also notable.

The Bioprocess Measurements Group remains focused on measurements and standards that support the needs of the agricultural, biomanufacturing, and pharmaceutical industries; homeland defense; and medical technologies. Of particular relevance and promise is the group's work to develop measurement standards and to provide data and reference materials for the detection of biothreat agents and for the safe, reliable testing of detection devices, as well as its work on remediation technologies, and in personnel training.

The Biomolecular Materials Group working on cell and tissue measurements has developed well-focused projects that include the following: development of quality-assurance and quality-control evaluation of collagen reference surfaces; fluorescence measurements for characterizing cytosolic green fluorescent protein (GFP) fluorescence intensity preservation in mammalian cultured cells; evaluation of the cytotoxicity of silicon nanoparticles and fluorescent dyes for the staining of live cells; and the use of calibrated and validated indicator cells on commercially relevant surfaces. Each of these projects has key stakeholders that are well defined (for example, the pharmaceutical industry, tissue culture plasticware manufacturers, cell culture reagent manufacturers, imaging tools/analysis manufacturers, and the FDA). The group has leveraged its cell metrology expertise to develop a successful program at

TABLE 3.1 Summary of Selected Outputs and Interactions of the Chemical Science and Technology Laboratory in FY 2004

Division[a]	Publications[b]	Talks	Committees[c]	Seminars	Conferences	CRADAs[d]	Patents Issued[e]	SRMs/ RMs[f]	SRDs	Calibrations[g]
830	1	20	12	8	1	0	0	0	0	0
831	120	152	39	3	22	3	1	8	2	0
836	65	45	76	13	5	1	0	1	0	682
837	38	90	80	10	4	4	1	3	5	0
838	86	114	83	21	5	6	0	2	16	0
839	71	159	135	36	6	3	0	135	0	323
Total	381	580	425	91	43	17	2	149	23	1,005

[a]830, Laboratory Office; 831, Biotechnology Division; 836, Process Measurements Division; 837, Surface and Microanalysis Science Division; 838, Physical and Chemical Properties Division; 839, Analytical Chemistry Division.
[b]Publications appearing in print in FY 2004. Another 165 manuscripts have been submitted for publication.
[c]Committee totals include 61 editorships and the Thermodynamics Research Center.
[d]CRADAs signed in FY 2004.
[e]There are a total of 44 active patents.
[f]SRMs/RMs (certificates issued).
[g]Calibrations were performed for more than 306 customers.
NOTE: CRADA, cooperative research and development agreement; SRM, Standard Reference Material; RM, Reference Material; SRD, Standard Reference Data.

the Hollings Marine Laboratory; the objective of this program is to determine optimal assays for monitoring cell state pre- and post-cryopreservation. In quantitative cell biology, the group met every milestone of the Tissue Engineering Competency Program (joint with the Polymers Division of the Materials Science and Engineering Laboratory) earlier than scheduled.

The Process Measurements Division's trace humidity work is particularly important to the U.S. semiconductor industry**.** The division has performed commendable work in chemical sensing using its "Micro-Hot Plate" to support the DHS. It should continue to build on the momentum and success it has achieved in collaboration with other government and industrial research and development (R&D) organizations to provide the fundamental scientific understanding, property data, and measurement standards for such promising microelectromechanical systems technology. This division's high-quality research and standards programs are clearly focused on meeting the needs of U.S. industry and government.

In the area of calibration, the Surface and Microanalysis Science Division has developed some highly accurate standards for testing explosive detectors, but they appear to have short lifetimes. Microencapsulation technology (which the Board suggested as a possible cure) was already under consideration. Related division work for the DHS that is focused on developing calibration standards for testing "drug-sniffing" instruments could be very significant. However, the division should ensure that the work it undertakes in responding to other agencies will indeed fulfill a real need; it should not hesitate to decline a request if its scientific and technical evaluation suggests that the work is likely to be irrelevant, even if successful.

The Analytical Chemistry Division develops strategic priorities in large part guided by feedback from major customer visits. Its other agencies (OA) funding and collaborative research activities are impressive. OA dollars have increased 23 percent, from $3.5 million in FY 2004 to $4.3 million in FY 2005 (projected)—a concrete demonstration of the relevance and technical quality of the division's research and services.

The Organic Analytical Methods Group has responded effectively to requests from other agencies and has anticipated future needs. Excellent examples of relevance and effectiveness include the group's work on dietary supplement SRMs (for the NIH Office of Dietary Supplements), marine health and bioscience applications (with the Hollings Marine Laboratory), forensic and homeland security measurements and standards, clinical standards (in support of the need of U.S. industry to meet directives of the European Union for in vitro devices), protein quantification (of general interest), brominated fire retardants in the environment, and the standardization of pepper spray canisters (at the request of the Department of Justice).

The Organic Analytical Methods Group is extremely efficient and productive. The group's clients include the National Oceanic and Atmospheric Administration; the Environmental Protection Agency (which increased funding significantly); the NIH Office of Dietary Supplement for Botanical Dietary Supplements; the National Institute of Justice (NIJ); the Office of Law Enforcement Standards—a NIST liaison group with the NIJ; the Defense Threat Reduction Agency; and recent NMIs with International Comparison Analyses. This group effectively disseminates its results and establishes priorities. An infusion of new scientific talent over the past few years has improved the group's visibility through publications and conference presentations. The laboratory will have a long-term impact on analytical methods and the well-being of marine animals by developing new methods to support environmental science.

RESOURCES

In general, the facilities and equipment of the Chemical Science and Technology Laboratory are excellent and provide CSTL staff the physical resources they need for their work. The Advanced

Measurement Laboratory (AML) has provided CSTL with much-needed, state-of-the-art space. CSTL staff expressed some concern about the quality of the space allocated to those divisions on the Gaithersburg campus that were not relocated to the AML. It appeared to the Board either that there was no plan for the renovation of existing space or relocation of these divisions to new space, or that any such plan had not been discussed in detail with the staff involved. CSTL management should work closely with the staff to develop plans for space and to keep them informed as these plans develop.

NIST has responded to concerns expressed in previous assessment reports of the Board about the quality of the Boulder facilities. They have been renovated and are now deemed acceptable by the Board members who visited the site during this assessment period. Equipment there is generally state of the art and meets the needs of CSTL researchers. The Analytical Chemistry Division, however, finds it difficult to acquire the equipment necessary for it to remain at the cutting edge of its field. In CSTL in general, it appears to be relatively easier to procure large, expensive analytical equipment (e.g., electron microscopes, surface analysis equipment) than it has been to keep essential, though less-expensive (about $50,000) pieces of equipment (spectrometers, chromatographs and so on) at state of the art.

In the area of human resources, CSTL is now at the point where attrition, due to retirements and the combination of flat budgets and maintaining competitive salaries, leaves it at risk of losing essential core competencies and unable to grow to meet metrology needs in rapidly expanding fields, such as the biosciences. The laboratory has lost 22 technical staff (nearly 10 percent) between 1999 and 2004 (see Figure A.3 in Appendix A), and a number of retirements are expected in the coming years. The CSTL has done an outstanding job of managing these losses, but it will be unable to fulfill its mission without an adequate increase in its budget to replace staff with essential skills and to hire new staff to develop those new programs that are essential in order to support emerging areas of science and technology. Salary increases are required to recruit and retain staff in all divisions, but this issue is especially acute in the biosciences, where competition for the best talent is severe. The following areas are essential to maintain and are in danger of disappearing: heat capacity, thermal conductivity, phase equilibria measurements, optical reference standards, optical imaging spectroscopy, primary pH measurements, and high-precision gas standards production.

The Analytical Chemistry Division has increased the relative number of postdoctoral fellows in an attempt to partially compensate for this loss of staff; however, this strategy is unhealthy for the long term. The Biotechnology Division continues to operate using a model in which individual principal investigators conduct their research independently, with very little staff support. This model is in stark contrast to that employed by nearly all other laboratories that conduct research in biology-related areas. The CSTL should consider increasing the ratios of technical support staff to Ph.D. investigators in order to improve efficiency. The Analytical Chemistry Division has successfully mitigated budget cuts by a careful analysis and restructuring of its cost recovery system; the other divisions should also critically evaluate cost recovery, where allowable, as a mechanism for increasing revenues to sustain existing efforts and to support new work.

4

Electronics and Electrical Engineering Laboratory

INTRODUCTION

Prior to the current assessment period, the Electronics and Electrical Engineering Laboratory (EEEL) had been organized in six divisions and two offices: Electricity Division, Semiconductor Electronics Division, Electromagnetic Technology Division, Radio-Frequency Technology Division, Optoelectronics Division, Magnetic Technology Division, Office of Microelectronics Programs, and Office of Law Enforcement Standards.

In 2003, a major reorganization took place: the Electricity Division and the Electromagnetic Technology Division merged into the new Quantum Electrical Metrology Division, and the Radio-Frequency Technology Division and Magnetic Technology Division merged into the new Electromagnetics Division. In addition, a major budget reduction caused two rounds of reduction in force (RIF) during fiscal years (FY) 2003-2005, with the reduction in the workforce totaling 45 personnel (see Appendix A, Figure A.4, for staffing trends).

The laboratory is now organized in four divisions, as shown in Appendix A, and continues to include the Office of Microelectronics Programs (OMP) and the Office of Law Enforcement Standards (OLES). Its divisions are these:

- Quantum Electrical Metrology (QEM) Division,
- Optoelectronics Division,
- Semiconductor Electronics Division (SED), and
- Electromagnetics Division.

MAJOR OBSERVATIONS

The Board presents the following major observations from its assessment of EEEL.

Significant accomplishments during this assessment period include the following:

- The overall technical quality of EEEL continues to be very high and innovative. The EEEL has an outstanding staff, a solid history of achievement, and close ties to customers. The projects are generally well aligned with the NIST mission and provide an excellent value for the money to the country and its industrial infrastructure.
- The merging of the former Electricity Division and Electromagnetic Technology Division into the Quantum Electrical Metrology Division has prompted a complete reexamination of all of the new division's projects and the manner and the extent of their support. The process is not yet complete, but it is already clear that this reexamination will force a more uniform assessment and support framework within the new division. This reexamination has had one immediate benefit in that other agencies (OA) opportunities are now being pursued more generally throughout the division. The Board commends the EEEL management on its prompt actions on realignment to strategic planning objectives.
- The Electronic Kilogram project is the best of its kind. Its work is on the threshold of changing the entire manner in which the International System of Units (SI) and the fundamental constants are defined and realized.
- Of particular note is the recent development of a portable Josephson voltage standard. There are about a dozen commercial Josephson array systems in North America, which allow customers to get the highest possible accuracy in a direct or indirect comparison. The portable standard has improved comparison accuracies by approximately an order of magnitude.

Opportunities for improvement at EEEL include the following:

- The reorganization and downsizing described above prompted two extreme responses among the staff—in some areas it was handled effectively, allowing new research directions to grow, but in other areas it created significant morale issues. On the whole, staff morale is still good, and many view their employment as a rich and exciting opportunity. However, the continuing strain on budgets and staff size are taking a toll and causing some staff members, including some of the best, to consider other career options.
- The equipping of the Advanced Measurement Laboratory (AML) is progressing extremely well. The only concern is whether future NIST budgets will allow this process to continue at a reasonable rate. These new facilities are excellent but very costly, producing a significant impact on the capital equipment funds available for other projects during this period.
- The shrinking budgets in FY 2004 and FY 2005 are threatening EEEL's ability to maintain its global leadership in a number of areas. Progress is being impeded by the inability to make timely hires, to refill vacancies, and to upgrade or in some cases even maintain research facilities.
- The mission and long-term plan for the Boulder campus of NIST are very unclear, which is affecting both the morale of and progress by the excellent scientists at that location.
- Metrology, though recognized as NIST's core competency, is being seriously compromised in recent years, particularly through funding competition with the Strategic Focus Areas. The EEEL should undertake a conscientious reexamination of this trend in order to reach a clear decision about the laboratory's level of commitment to metrology and to develop a strategy for implementing the decision. It is particularly necessary to communicate clearly to the staff where metrology lies on NIST's priority list.

TECHNICAL QUALITY AND MERIT

The technical quality and merit of research and services carried out by EEEL continued at a very high level during this assessment period. Many projects are on the cutting edge of advancing scientific knowledge, and advance the standards and calibration services that the laboratory is asked to perform. The following discussion indicates some of the projects that stand out for excellence and illustrate the merit of the laboratory's work in brief.

The work of the Electronic Kilogram project (to define the kilogram by electrical standards) has reached a milestone in realizing a recent electronic determination of the kilogram that has much lower uncertainty but is still consistent with previous results. These NIST results make a major contribution to a new value for Planck's constant (Mills et al., 2005). The project team is participating in international discussions on redefining the kilogram, based on a consensus definition of Planck's constant. Such a definition could result in substantially lower uncertainties of almost all of the electrical quantities, including voltage, resistance, and current. The adoption of the electronic kilogram as the mass standard would improve the consistency of the International System of Units and would also provide better determinations of many fundamental physical constants, such as the charge and mass of the electron, that serve the general scientific and technological communities.

The space imaging of the present space observatory, the Submillimeter Common-Use Bolometer Array (SCUBA), is impressive; SCUBA is the second-most-referenced telescope, following the Hubble Space Telescope. The planned SCUBA 2 system, with its array of about 10,000 superconducting transition edge sensors designed and fabricated by the Quantum Sensors project, offers 100 to 1,000 times more spatial resolution or mapping speed, as well as substantial improvements in the low-level detection limit. The new SCUBA 2 system will be installed on the James Clerk Maxwell Telescope in 2006. This is excellent work at the exotic frontiers of measurement.

The DNA fingerprinting project is a good example of how to combine biology with nanoelectronics. The project has good external support, showing the quality of the work. The project is a good example of how basic technology, in this case microfluidics, developed at NIST can be applied to systems that have both commercial and defense applications. While the techniques currently being developed are aimed at DNA fingerprinting, it appears that the core technology will lead to several new biological applications.

A second activity that continues to grow is single-molecule manipulation, which is a real strength of the group that performs this work. As part of this activity, the nanoparticle and nanopore field is becoming more mature and very competitive. This may be an opportunity for NIST to take a leadership role in the metrology of nanopores and nanoparticles. This group is vibrant, and recent personnel additions should enhance its productivity even further.

The work on optical frequency combs is outstanding. The technology is now solid enough that critical applications can be pursued. The group performing this work should consider a collection of possible key applications, analyze their potential, and choose one or two of them to focus on. These should be applications for which the impact of this new technology is substantial and the business vision predicting that impact can be clearly articulated. Once chosen, these applications should be aggressively pursued.

The high-speed Electro-Optic Sampling (EOS) project is at the leading edge and is an outstanding capability with powerful applications in metrology. This project is a collaborative effort between the Electromagnetics and Optoelectronics Divisions. An on-wafer EOS system for phase and waveform time calibrations was developed. The team established calibration methods and uncertainty analyses in coaxial media up to 110 GHz and on-wafer to 200 GHz. This capability is expected to migrate as a fundamental phase and time-domain quantity. It will have significant impact for the optoelectronics as well as the semiconductor industry. In related work, the Electromagnetics Division has developed an accurate method of measuring the characteristic impedance of a transmission line on lossy silicon substrates and on-wafer calibration using this method. The division also developed instrumentation and methods for accurately and completely characterizing multiports and small printed coupled lines.

The accomplishments of the Electromagnetic Properties of Materials project are impressive. They support metrology and technology for bulk, thin-film, liquid, and biological materials. The team remains the best materials measurement center in this arena. It has the broadest and deepest capabilities in this area. This team supports many projects, some of which seem to be specific to one customer. Industrial growth in the life sciences areas is much larger than in electronics. There should be more emphasis on the life sciences aspects of the materials work.

RELEVANCE

The Electronics and Electrical Engineering Laboratory addresses relevant needs of U.S. industry in the extremely broad area of electrical measurements. Today, this scope includes the characterization of devices for optoelectronics and micro-/nanoelectronics and the associated manufacturing technologies. Responding to the growing breadth of this challenge requires EEEL to carefully prioritize the areas in which to deploy its resources, mainly addressing the most technically demanding and those that have the most metrological impact for the laboratory's customers. Ideally, there would be a steady procession of new calibration capabilities fed from EEEL's research that are developed and offered to customers, while others are phased out and given over to second-tier calibration laboratories. For example, a major fraction of the activities of the EEEL Quantum Electrical Metrology Division is directly related to maintaining and disseminating electrical measurement standards for voltage, resistance, current, impedance, power, and energy over extensive ranges and at very low uncertainties. The customers for these services represent manufacturing, power utilities, process control companies, the semiconductor industry, the military, and the aerospace, transportation, and communications sectors. In this way the division has a direct impact over an extremely broad fraction of the total American infrastructure.

The QEM Division's Electric Power Metrology project is an example of direct impact at a relatively small number of power utilities and equipment manufacturers that in turn has a very broad, positive, secondary impact on every American. The QEM Division's Voltage Metrology project is directly relevant to a larger number of customers and also indirectly impacts most Americans, although its visibility to them is typically reduced by more layers of measurement traceability.

The EEEL generally does a commendable job of balancing such near-term development with long-range metrology research. A good example on the long-range side is the QEM Division's Electronic Kilogram, a project with more relevance to the fundamental knowledge base than to near-term industrial applications. It is in a unique position to have profound impact on all of measurement science in every National Metrology Institute in the world, but industry will barely notice these results in the immediate future.

The relevance of EEEL is often enhanced by cross-campus collaboration, such as the linkage between the QEM Division's Nanoscale Cryoelectronics and Single Electron Tunneling projects. Jointly, this work is addressing one of the fundamental challenges of metrology, the quantum metrology triangle, and the results are being eagerly watched by the international metrology community. The metrology triangle experiment consists of developing a quantum Ohm's law from three effects: Josephson, single-electron tunneling, and quantum Hall. The completion of the quantum metrology triangle through the Nanoscale Cryoelectronics project's single-electron counting capacitor will be important for fundamental science and metrology.

An example of interlaboratory collaboration is provided by the work of the EEEL Electromagnetics Division with the Physics Laboratory in exploring a fundamentally new approach to microwave power measurements. A direct comparison system for WR-15 and WR-10 waveguides has been constructed, and new WR-15 and WR-10 calorimeters have been designed. This project area still represents a very valuable fundamental NIST capability that is needed in the industry. The immediate need is to complete the capabilities in 1.85 mm (67 GHz) and 1.0 mm (110 GHz) connectors to support high-frequency coax already widely deployed in industry. The emerging goals are above 1.0 mm (110 GHz). Many of the existing services at lower frequencies are stable and mature. These should be considered for transfer from NIST to other laboratories, which could free up key resources for the effort at higher frequencies.

Collaboration that is interdivisional, interlaboratory, and even external (to NIST) on projects of relevance to the microelectronics industry are promoted by the EEEL Office of Microelectronics Programs. In spite of its relatively small budget, this office continues to be successful in starting and managing a broad portfolio of NIST programs in support of industry. The collaboration of OMP with the Semiconductor Manufacturing Technology Consortium (SEMATECH) is also effective in generating funding for NIST programs, as highlighted in the NIST work on low-dielectric-constant interconnection metrology using the small-angle X-ray scattering facility.

A project of particular relevance to national defense is the Electromagnetics Division's application of reverberation chambers to calibrating radio-frequency (RF) field probes to speed the calibration process for the U.S. Army. This Complex Fields project has demonstrated a potential weakness in existing field probe systems that can result in personnel being exposed to excessively high fields without being aware of the hazard. These results should be followed up with both the Army and probe suppliers to improve understanding of this vulnerability and to redesign probe systems to eliminate it.

The Semiconductor Electronics Division of EEEL is conducting an appropriate mix of near-term and long-term research and development (R&D). Currently more than half of its projects are focused on specific items already identified as being of immediate priority by its industrial customers. One example is SED's Electrical Test-Structure Metrology project. The International Technology Roadmap for Semiconductors (ITRS) has repeatedly stressed the need for improved critical dimension (CD) metrology traceable measurement standards. The development of an adequate CD metrology infrastructure is essential in order to support the technical and manufacturing needs of optical lithography below 100 nm. At the present time, there is no established technique that meets the stated requirements. In response to this need, SED has developed three-dimensional CD standards fabricated in single-crystal silicon with nominal widths as low as 40 nm. In collaboration with NIST's Manufacturing Engineering Laboratory (MEL) and Information Technology Laboratory (ITL), SED has developed an improved measurement and data analysis procedure to minimize the expanded uncertainty associated with the reference features. The second-generation units have CDs as low as 45 nm and uncertainties, based on statistical analyses performed by personnel of ITL's Statistical Engineering Division, of between 1.5 nm and 3 nm. In cooperation with MEL and ITL, SEMATECH, and VLSI Standards, Inc., 10 chips containing the improved NIST-calibrated CD reference features were distributed to SEMATECH's 10 member companies in 2004, along with a Technology-Transfer Report.

The Optoelectronics Division of EEEL is engaged in very relevant work on single-photon devices, including sources and detectors, which are key enablers for advances in quantum technology. The new quantum technology holds great promise for a multitude of new devices and systems, including fully secure optical communications, a current high-priority need. The customer focus and market outreach of this work has resulted in steady growth in terms of projects and calibration income.

The Optoelectronics and Electromagnetics Divisions both had calibration income growth in FY 2004, with that of the Quantum Electrical Metrology Division holding roughly constant. As a whole, EEEL calibration income in FY 2004 recovered from an approximately 10 percent drop in FY 2003, but it is still flat when analyzed over several years. In the growth areas, services are focused on a sufficiently wide customer base so that if there is a downturn in one sector, the revenue income does not suffer greatly. Such growth is an indication of the relevance of this activity to the industry.

EFFECTIVENESS

The EEEL continues to demonstrate effective and timely delivery of results to its customers. For example, the Farad and Impedance Metrology project of the QEM Division recently responded to a customer's request to greatly improve the world's best capacitance accuracies in the range of 20 Hz to 20 kHz. Applying a novel technique related to their primary standard, the Thompson-Lampard capacitor, the division successfully completed this project and now offers these accuracies as a regular calibration service. The improved uncertainties have impact not just for the initial customer but also among a much larger subset of customers who use high-accuracy capacitance bridges or precision capacitance standards. The initial customer had originally sought calibration services abroad but now has improved the specifications and traceability of its products on the basis of the NIST developments. This is an excellent example of the division's responsiveness to customers' demands as well as of its success in realizing an effective solution.

Another core capability in which EEEL continues to enhance capability as well as efficiency of dissemination is the QEM Division's maintenance of the U.S. legal volt. This unit is provided as an internationally consistent, accurate, reproducible, and traceable voltage standard that is readily and continuously available for the national scientific and industrial base. Of particular note is the recent utilization of a portable Josephson voltage standard for direct calibration of customer Josephson voltage systems. This couples NIST's expertise with hysteretic Josephson junction operation and the novel design of a compact, easily operated Josephson array system specifically designed for transport to customers. There are about a dozen commercial Josephson array systems in North America, which allow customers to get the highest possible accuracy in a direct or indirect comparison. The portable standard has improved comparison accuracies by approximately an order of magnitude. In an effort to improve EEEL efficiency while maintaining a leadership role, this project is playing a key role in a comparison of 10 V Josephson array systems within North America. By using its portable Josephson array system, NIST will act as the pilot laboratory. However, instead of measuring in each loop of the comparison, NIST will only measure directly with four subpilot laboratories, which will then measure with respect to the rest of the participating laboratories. This system promises to reduce the uncertainty of the overall comparison and still reduce the number of measurements required at NIST, enhancing EEEL's efficiency.

The Electromagnetics Division's Scattering Parameters project has demonstrated exemplary effectiveness for military customers by delivering updated Six-Port Systems to the Navy, a suite of vector network analyzer software to the Air Force Primary Standards Laboratories, and a 30 MHz attenuator system and capability to the Army Primary Standards Laboratory.

The Electromagnetics Division has also been particularly effective in the Reference Fields and Probes project area, which is providing important support to standards work in the area of test-facility qualification at frequencies above 1 GHz. Qualification of test facilities at frequencies below 1 GHz is well understood in the electromagnetic compatibility community, but significantly less experience is available for frequencies above 1 GHz. The design for the co-conical field generation system being developed for the U.S. Air Force has been completed, and it is intended that a system will be delivered to the Air Force in 2006. This tool will provide a system for rapid, cost-effective probe calibration over the frequency range of 10 MHz to 45 GHz.

In response to the need for improved integrated-circuit CD metrology referred to in the section above on "Relevance," the Semiconductor Electronics Division's Single Crystal Critical Dimension Reference Materials project has developed three-dimensional CD standards fabricated in single-crystal silicon with nominal widths as low as 40 nm. As stated, in collaboration with NIST's MEL and ITL, SED has developed an improved measurement and data analysis procedure to minimize the expanded uncertainty associated with the reference features. This expanded uncertainty is derived statistically from the calibration function, which enables tracing the atomic-force microscopy (AFM) measurements to the silicon lattice-plane spacing using high-resolution transmission electron microscope (HRTEM) imaging. The previous generation of reference materials, which was delivered in 2001 and used electrical CD as the transfer calibration, had uncertainties of approximately 14 nm. The second-generation units have CDs as low as 45 nm and uncertainties, based on statistical analyses performed by personnel of ITL's Statistical Engineering Division, of between 1.5 nm and 3 nm. This decrease in uncertainty is of major importance to the end user of these reference features, as demonstrated by a cooperative effort between NIST's MEL and ITL, SEMATECH, and VLSI Standards, Inc. This collaboration distributed 10 chips containing the improved NIST-calibrated CD reference features to SEMATECH's 10 member companies in 2004, along with a Technology-Transfer Report. These reference materials were delivered with sub-100 nm CDs and combined uncertainties of less than 5 nm. The improvement in uncertainty resulted from the implementation of a new type of HRTEM-target test structure, the extensive use of SEM inspection to identify targets with superior CD uniformity, and the use of advanced AFM to serve as the transfer metrology.

This year, the Semiconductor Electronics Division again contributed significantly to the effectiveness of EEEL by organizing (with SEMATECH) the 2005 Conference on Characterization and Metrology for ULSI [ultralarge-scale integration] Technology, a biennial event that is the major technical conference in this field for the semiconductor industry and its R&D partners in academia and government.

This type of effectiveness in outreach to industry is also demonstrated by the Optoelectronics Division, which continues to sponsor the Symposium on Fiber Optic Measurements. Although attendance at this event has decreased from its peak, the decrease is far less than one might expect given market conditions, reflecting the importance placed on this meeting by the core community of attendees. As the optical communications market recovers, the symposium will be well positioned as a forum for advanced research in fiber metrology and related fields.

The Optoelectronics Division has also shown its effectiveness by working with the National Institute of Justice on developing optical techniques for the testing and measurement of body armor. While this application is unlikely to lead the Optoelectronics Division into major new frontiers of optical sensing, it is a good example of how the division can apply its fiber-optics expertise to diverse and important applications areas. This application is interesting, challenging, and important.

The Advanced MOS [metal-oxide semiconductor] Device Reliability activity is a very good example of how NIST can impact U.S. industry. With continuing device scaling, the gate dielectric film thickness has decreased to an oxide-equivalent value of 1.1 nm in 2005 and 0.7 nm or less by 2010. This has been identified as a critical front-end technology issue in the Semiconductor Industry Association Technology Roadmap. There is great interest in the semiconductor industry in the development of high-k dielectrics. Another important aspect of high-k gate dielectrics is the development of models to explain dielectric degradation. This technology need has prompted the MOS Device Reliability Program to shift its research focus to study high-k dielectrics with metal gate electrodes. In 2004, the NIST group continued to be successful in making significant contributions to the study of high-k dielectric reliability. Among the recent accomplishments of the group are characterization of the energy dependence of interface traps in hafnium oxide (HfO_2); publication of the new Joint Electron Device Engineering Council standard, JESD-92, for soft breakdown of ultrathin gate oxides; completion of the study of progressive breakdown in small-area ultrathin gate oxides; and study of anomalous threshold voltage roll-up behavior in HfO_2 metal oxide silicon field-effect transistors.

RESOURCES

As discussed in the following subsections, lack of laboratory resources in the Electronics and Electrical Engineering Laboratory is cause for serious concern.

Funding

Funding for EEEL during the current review cycle has been severely reduced; this restriction is having a detrimental effect on some promising activities. As noted in the October 2004 EEEL Operational Plan, "Continued flat and shrinking budgets are threatening the Laboratory's ability to maintain its global leadership in a number of areas. Progress is being impeded by the inability to make timely hires, to re-fill vacancies, to upgrade or in some cases even maintain research facilities. This impact is especially felt in fundamental metrology research . . ." (NIST, EEEL, 2004, p. 2). This same observation has been emphasized and reiterated by the Board for the past several years. The budget issue is, more than ever, severely felt in this review cycle, with two rounds of RIFs implemented.

Since the Board's previous report, in 2003, EEEL has undergone reorganization in an attempt to better align work groups and to reduce expenses. The shrinking EEEL budget can be expected to have a significant negative impact on U.S. industry. As noted in past reports and reflected in the EEEL Operational Plan, "There are several areas in which NIST is at risk of becoming outdated or losing its world-class status due to lack of funds. . . . The current scope of the Electromagnetics Division cannot be maintained as is with its current budget. While other agency funding might help fill in the gaps, it also creates a trade-off between sponsor and agency objectives, and is difficult to obtain in those calibration areas core to the NIST mission" (NIST, EEEL, 2004, p. 22). The budget reductions remain an ongoing problem for the division as well as for all of EEEL.

Metrology

The Board views with concern the emphasis of EEEL shifting from the core mission of metrology to technology-development programs, which appears to be driven in large part by budgetary sources favoring the latter. This change is of particular concern since the current NIST Strategic Plan is uniformly expansionist, and NIST's budget has very recently increased, in stark contrast to the budget contractions in EEEL; it is exceptionally damaging to technical productivity for the sunset of an initiative to be implicitly communicated by means of its budget or RIFs rather than through a clear strategic plan that allows for the orderly conclusion of work.

Several key activities have been heavily publicized because they are of fundamental importance to electrical metrology. (These include the Capacitance Standard Based on Counting Electrons, Johnson Noise Thermometry, the Arbitrary Waveform Josephson Array Generator, and the Electronic Kilogram.) Each of these activities has experienced a reduction in resources to the extent that, although there may be continued support for the short term, there is concern that their outputs will be substantially reduced. This broad reduction in mission-aligned projects that serve to showcase NIST's excellence will tarnish NIST's international reputation and have a chilling effect on the future hiring of top researchers.

Facilities

The concern with the highest priority involves the inadequate resources assigned for the Nanofabrication (Nanofab) facility. Currently there are three technician slots assigned to this facility.

The Board believes that this number should be at least six for a facility of this size and complexity. Also, there is some concern about using contract labor for process development. While this approach will bring in critical expertise to get unit processes qualified, it will still be important to have in-house process engineering support to maintain and tweak processes. The operating budget is low, but that may be because there are more operating costs covered by NIST upper management than comprehended by the Board.

The second-ranking area of concern is the low level of activity on back-end metrology needs. As back-end dimensions and process control push the limits of current metrology, there is a growing need for new metrology techniques and standards for back-end processing (process steps from contact through completion of the wafer prior to electrical testing). A specific example of how this could be improved would be to better define the objectives of the Cu back-end metrology project. It is important that the back-end projects look far enough out at industry needs to allow the research to stay ahead of industry requirements.

The setting up of the Advanced Measurement Laboratory caused financial fluctuations for other activities. While this situation may have been inevitable, management should be persistent in stressing that such fluctuations are temporary and that important projects closely aligned with the laboratory's mission will continue to be supported. Such assurances are necessary to keep morale buoyant and to retain key researchers during this turbulent period.

The Board has commented in past years on the proposed RF EM-Field Metrology Laboratory (REML) facility in the Boulder area. The EEEL Operational Plan states: "The Electromagnetics Division facilities are becoming inadequate for the next generation of EMI, EMC, wireless and radar measurements for industry. The EEEL strongly supports an initiative for the construction of the new world class 'RF EM-Field Metrology Laboratory Facility' (REML). This would cost approximately $30M and would fund a new large high bay facility with a basic set of metrology-focused electromagnetic (EM) test chambers to address a wide range of topics, including EM compatibility of electronic products, bioeffects of EM fields, international standards affecting commerce, and basic research related to measurement and characterization of EM field quantities" (NIST, EEEL, 2004, p. 23). The Board is not aware of the details of this laboratory that would drive the estimated cost to $30 million, but it fully supports the need for the development the REML facility to replace the deteriorating facilities presently available in Boulder and to enhance the capabilities for this work within the laboratory.

Staffing

The Board has noted in the past the need for succession planning as key staff members approach retirement. This is noted in the EEEL Operational Plan: "Not only is it difficult to make timely hires, but it is also difficult to provide the appropriate rewards and incentives to maintain excellent staff members. Many areas in EEEL are only 1 or 2 experts 'deep,' whom the Laboratory can ill afford to lose" (NIST, EEEL, 2004, p. 22). This issue will only continue to accelerate unless steps are taken to address it.

5

Information Technology Laboratory

INTRODUCTION

The Information Technology Laboratory (ITL) has responsibility for information technology, telecommunications, mathematics, and statistics. The laboratory staff is organized in six divisions, as shown in Appendix A:

- Mathematical and Computational Sciences Division (MCSD),
- Advanced Network Technologies Division (ANTD),
- Computer Security Division (CSD),
- Information Access Division (IAD),
- Software Diagnostics and Conformance Testing Division (SDCTD), and
- Statistical Engineering Division (SED).

Appendix A also presents the staffing trends for the laboratory (see Figure A.5).

MAJOR OBSERVATIONS

The Information Technology Laboratory is a vital resource, both to other NIST laboratories and directly to the United States and the world. It has an outstanding program—a conclusion based on six factors:

1. The work of many individual scientists in ITL is excellent.
2. Some of the work (for example, in security testing) has already had a major impact on formal national and international standards as well as standards agreed to by vendors across industry boundaries. Specific examples of standards impact are given by way of illustration throughout this chapter. Much of the work of ITL has the potential for making a significant difference in global commerce, and the Board expects that other work will likely have a similar impact on standards.

3. The ITL uses many mechanisms to disseminate its work effectively, including formal standards bodies, professional collaborations, technical papers, workshops, conferences, software, Web-based tools, and collaboration with other government agencies.

4. The disciplines in ITL are at the heart of major U.S. initiatives, including homeland security, electronic voting, and the supporting information systems for health care.

5. Two ITL divisions (the Mathematical and Computational Sciences Division and the Statistical Engineering Division) provide fundamental tools and expertise for many measurement, standards, and technology activities throughout NIST. All are a fundamental part of programs across NIST or with other government agencies. Thus, ITL scientists are enablers for other NIST programs as well as being direct contributors to information technology (IT)-specific activities.

6. The Board anticipates significant impact from the work reviewed during this assessment period based on its excellence and alignment with key needs and on a track record of impact from previous work.

Different laboratories have different missions and different pressures. Currently, ITL is active in a large number of mandated programs (principally in the areas of homeland security and information security) that constrain its activities in ways that university laboratories or some foreign government research laboratories, for example, are not constrained. Recognizing these limitations, ITL compares favorably with top-ranked U.S. government laboratories.

This conclusion does not apply to every ITL project reviewed. In any large research laboratory there will inevitably be varying levels of success across projects and some projects that are viewed as questionable by some reviewers; if this is not the case, the laboratory is not including enough higher-risk projects in its portfolio. In addition, no other laboratory used for comparison has a mission with a primary emphasis on standards and metrology, and this difference in mission must also be taken into account.

The ITL portfolio of projects has wide range and distribution. The Board believes that ITL compares favorably with other government laboratories. The primary concern of the Board comes in part from the success of ITL. Because information technology is at the heart of so many vital changes in our world, and because ITL has been very responsive to needs from Homeland Security, Help America Vote, and Electronic Health Records activities, for example, ITL finds itself at the heart of these and other mandated government initiatives. This role has required ITL to put more and more of its resources into increasingly short-term requirements. The Board is concerned that this shift will undermine the ability of ITL to anticipate future needs of both industry and government. Additional longer-term, stable funding would enable ITL to look at some longer-range areas and to backfill some skill areas that have become very thin or nonexistent during a multiyear period of declining funding.

In spite of the pressures of short-term, mandated programs and the challenges of low funding, morale seems to be very high in the laboratory. The recent NIST Employee Survey supports this observation, placing ITL first or second among the NIST laboratories in 10 of the 15 categories surveyed, and above the median in all categories.

Rather than covering all of the programs and projects within ITL, the discussions below provide examples within the assessment categories (technical quality and merit, relevance, effectiveness, and resources). The Board has highlighted a small number of programs that demonstrate the nature of the work in ITL. In many instances, a particular program could have been reiterated within each assessment category. However, because these are illustrations rather than reviews of all programs and projects, discussion of the same project is not repeated across categories. Hence, lack of mention of a particular program or project is not an indication that the work was somehow considered less important than those mentioned.

TECHNICAL QUALITY AND MERIT

The Information Technology Laboratory ranks with the best of the U.S. government laboratories in the quality and merit of its technical work. The technical quality of the work is uniformly very high across all six divisions.

Four ITL scientists were recognized with the Department of Commerce Gold Medal for their work in Smart Cards. Along with two colleagues from the Manufacturing Engineering Laboratory, two ITL scientists were awarded the Silver Medal for their work on Two Dimensional Grid Standard Reference Material. Seven scientists from four different projects were awarded Bronze Medals. One staff member received the NIST 2004 Allen V. Astin Award for advancement in measurement technology. The long list of staff publications reflects the quality of work and the focus on standards groups both nationally and internationally. Outside awards to ITL staff members (e.g., appointments as an Institute of Electrical and Electronics Engineers fellow and an American Society for Quality fellow, receipt of the Technology Review Top 5 Patent from the Massachusetts Institute of Technology, several awards from the International Committee for Information Technology Standards, and selection to the National Academy of Engineering) further speak to the strong technical work of the laboratory.

The projects reviewed generally evinced high technical quality because of the caliber of the scientists, the significant accomplishments in the work, and the collaboration with other scientists enabling breakthrough work that could not be done in isolation. Following is a discussion of examples in quantum computing, the digital mathematical library, statistical key comparisons, digital health care, and computer security. These projects, selected from many, typify the highly collaborative work of ITL and demonstrate very different examples of the excellent work.

The quantum computing work is perhaps the highest-risk area of projects reviewed by the Board in that there is a long way to go before practical implementation, let alone standardization of quantum computing. Generally, ITL work in this area is a collection of individual projects functioning under a large umbrella. At some point, it would be important for ITL to have an interdisciplinary team review the components in order to establish unity of purpose and goals. Nevertheless, the technical work is outstanding. It is carried out with Defense Advanced Research Projects Agency (DARPA) funding, in collaboration with the NIST Physics Laboratory (PL) and Electronics and Electrical Engineering Laboratory (EEEL), and it cuts across multiple divisions of ITL. For example, an ITL staff member was a key contributor to a recent series of landmark NIST experiments demonstrating key steps for quantum information processing in ion systems: teleportation (Barrett et al., 2004) and the semiclassical Fourier transform (Chiaverini et al., 2005).

The work by ITL on the Quantum Information Systems project involves the Mathematical and Computational Sciences Division, Advanced Network Technologies Division, and Computer Security Division, working with scientists from PL and EEEL, with partial support from DARPA. The goal is to advance the science in quantum computing, leading to the ultimate goal of creating a useful quantum computer, and to develop secure quantum communications systems.

Recent results showed a 3 percent failure rate of quantum gates, which is several hundred times larger than the rate scientists had generally thought necessary to produce useful results. But ITL mathematicians have shown that even with this high error rate, a new fault-tolerant architecture can produce reliable and useful results. A NIST researcher cautioned that while this work reduced the gap between theory and practical reality, showing that quantum computing may be easier than had been thought, it will take a lot of work to build a useful quantum computer.

In quantum communications, two important steps have been taken: (1) network scientists from ANTD, in collaboration with PL colleagues, have achieved a quantum key exchange rate of 1.0 megabits per second, the highest rate achieved over a free-space quantum link; and (2) CSD scientists have shown vulnerabilities in the proposed quantum key distribution protocols and are working on remedies for these.

The ITL has been addressing the move to digital health care systems. In 2003, spending for health care in the United States was $1.7 trillion, according to a 2004 study from the Centers for Medicare and Medicaid Services (Smith et al., 2005). The Institute of Medicine reported that 44,000 to 98,000 patients die each year from preventable medical errors (IOM, 2000). Subsequent research has found that patients are at the highest risk for medical error when they are prescribed and administered medication and when their care is transferred from one provider or facility to another.

Information technology provides a great deal of potential for decreasing error rates in both of these situations, as well as for reducing costs and increasing access to specialty care. Some of the relevant technologies include the following:

- Electronic health records (EHRs),
- Computerized physician order entry (CPOE) systems,
- Document management systems that enhance information sharing among health care providers,
- Wireless pervasive computing devices on a local or body area network,
- Telehealth clinical specialty applications,
- Digital medical imaging, and
- Collaborative decision-support tools at the point of care.

Both CPOE systems and EHRs rely on the Health Level (HL)7 standards effort with which ITL is heavily involved. CPOE systems are used specifically for pharmacy orders; they can reduce or eliminate errors related to illegible handwriting, easily confused drug names, and other factors. In addition, the emerging environment must be secure and reliable, it must protect privacy, and it must be able to interoperate across a wide range of independent facilities.

The ITL team has formed a crosscutting initiative looking at technology and standards issues across all of the ITL divisions. This is an excellent effort addressing an important problem area that requires both the technical and standards focus that NIST ITL can uniquely provide.

The individual components of the work in technology that supports health care are excellent. For example, the work on networking standards focused on performance metrics (throughput, delay, jitter, loss) in realistic medical scenarios in which there is a requirement for communication across disparate medical devices. The statisticians were also engaged in this part of the project. The security scientists were concerned with the protection of electronic records against various threat scenarios, assuring the ability to achieve reliable results while meeting the privacy standards of the Health Insurance Portability and Accountability Act of 1996 (HIPAA). The software group addressed the conformance testing and standards needed to share documents across multiple environments. The work described here represents only a sample of the health care initiative.

While this work has a framework that ties the projects together, today it is primarily a loose consortium of projects with a common motivation. This is an appropriate place to start, creating interest and motivation for work across the divisions of ITL. Ultimately, for maximum success, an integrated project structure will be needed in order to ensure best results not only for the components but for the whole.

The Digital Library of Mathematical Functions (DLMF) is another long-term project, but it involves much lower risk than that for quantum computing. Here the goal is to replace the NIST best seller, Abramowitz and Stegun's *Handbook of Mathematical Functions* (first published in 1964), one of the most widely used mathematics books in the world but now extremely out of date. Rather than simply updating the volume, MCSD has chosen to make advanced use of extensible markup language/math markup language (XML/MathML) software capabilities. The DLMF will have a substantial network of hyperlinked and cross-referenced formulas. In carrying out the project, ITL scientists have drawn on researchers from around the world for writing, reviewing, and testing new chapters. This work will be an important resource for scientific computation done around the world. The cutting-edge use of MathML for presenting mathematical formulas, the best existing example of this standard, is impressive.

Statistical methodology is at the heart of reliable and comparable measurements and standards, and hence it is central to the mission of NIST. Through the work carried out in one project, the international Mutual Recognition Arrangement (MRA) signed by the United States and more than 80 other nations established an official international policy for recognition of equivalence of weights and measures. This project was implemented through NIST and the National Metrology Institutes (NMIs) of other countries. The ITL is working with scientists across NIST and throughout the world developing and applying statistical methodologies for the key comparisons that implement the MRA and support the statements of NMIs' certified measurement capabilities that are fundamental to world trade.

The Computer Security Division's programs in security testing are outstanding. The Cryptographic Module Validation Program (CMVP) and Crypto-algorithm Validation Program (CAVP) are models that analogous laboratories around the world emulate. This is evidenced by the adoption (or planned adoption) of Federal Information Processing Standard (FIPS) 140-2 procedures by the United Kingdom and possible expansion to Korea, France, and Germany, and by ongoing work to incorporate FIPS 140-2 into the Common Criteria. These programs find a high rate of security flaws (20 to 50 percent in CMVP, depending on the previous experience of the submitter), and they find about 30 percent of the products to be nonconformant (via CAVP). Finding these problems before hackers do is a significant accomplishment. This excellent work will have impact on the increasingly important area of computer security.

A factor in evaluating the overall quality and merit of a laboratory is the balance of the work in the context of the laboratory mission. That involves asking whether there is an appropriate mix of short- and long-range projects and a sufficient number of high-risk, high-payoff projects in the portfolio to provide insurance for the future. The ITL displays good balance between short- and long-term projects, although it has moved toward more short-term projects over the years (this varies by division). "Long-term" is not synonymous with "high-risk" (for example, the Digital Library of Mathematical Functions is very long term and involves a large number of external people, but it is on a very clear path).

The majority of the short-term work arises in mandated programs and has external funding. The increased reliance on this funding and ITL's central role in many mandates (homeland security, health care, and electronic voting, for example) is slanting the laboratory toward a narrow range of issues. The extent to which federal mandates may be enervating the divisions by refocusing work on security is an issue to be watched carefully by laboratory management in the future. Another danger of excessive short-term focus is that it could ultimately undermine the ability to anticipate new issues that will arise.

It is also necessary to ask whether the work is sufficiently distinct from work done elsewhere. Because of the unique NIST mission in standards and metrology, it generally makes little sense for NIST to use its scarce resources to compete with research work done elsewhere. Generally during this assessment period, ITL's projects were either part of mandated work (e.g., related to homeland security); were essential to standards and metrology (e.g., involved Domain Name System [DNS] security); undergirded fundamental measurement science (the work of the Statistics Division fits in this category, as the scientists define the measurement and validation practices across NIST); or were sufficiently distinct from outside work. Of the projects reviewed, only in quantum computing does the Board question the role of NIST, not because of the caliber of the work, but because this work is still in the fundamental science realm and is a long way from the issues of standardization.

RELEVANCE

The relevance of the efforts of ITL involved both its customer focus and its responsiveness. The laboratory has been responsive to many initiatives within NIST—homeland security, voting, World Trade Center analysis, and health care, to name a few. Relevant work on these initiatives has been carried out by all of the ITL divisions. As stated above, the laboratory may be becoming overwhelmed by mandated (and often underfunded) work, to the detriment of maintaining a stable, long-term laboratory able to respond to future as well as present needs.

For example, the Statistical Engineering Division statisticians have collaborated with scientists in the Building and Fire Research Laboratory in an analysis of the collapse of the Twin Towers at the World Trade Center. The SED has provided the statistical design for experiments and model simulations to discover the sequence of failure events and to determine the relative importance of the several failure modes (impact, fire, heat, structural elements). This one of many examples underscores a common theme in ITL. Since computing, mathematical modeling, and statistical analysis are fundamental to all areas of science today, ITL plays an important role in providing expert collaboration throughout NIST. This work is aided by software tools and training that the staff does for other parts of NIST. In turn, this keeps the ITL scientists abreast of key developing needs and feeds back into programs in ITL. The ITL staff does this so well that the contribution they make throughout NIST on other projects is sometimes taken for granted and underappreciated.

Relevance in ITL is not limited to those areas in which the laboratory responds to outside requests, however. The way that its scientists seek out key connections across all of ITL's programs continues to be impressive. There is a notable and growing strategic nature to these connections. Any scientist can find someone interested in his or her work; it is another thing to be tied in to the customers whose use of the results can have high impact. This latter attitude has become ingrained in the thinking of ITL to the point that many of the ITL publications are in journals of interest to the customer, and very few projects are taken on with no sponsor. By necessity, this has meant that work has become more short term simply because it is focused on a defined problem. ITL should push back the boundaries to better anticipate future needs.

An example of this is the First Responders program in ANTD. During the events of September 11, 2001 (9/11), there was difficulty in linking all of the messages from the disparate response communications because of issues of wireless, localization, interference, and ad hoc networks. The network scientists have been developing testing methodologies and standards enabling future interconnection of a range of devices and networks.

Following voting irregularities in the 2000 elections, there has been a strong push to solve the problem with technology. The ITL sponsored the First Symposium on Building Trust and Confidence in Voting Systems, looking at a variety of ways to support electronic voting. ITL scientists have been working in the areas of security, interoperability, and human factors. The group has a goal of updating the standards in early 2006. This is good work, but the scientists should broaden their scope, looking at ways of ensuring the reliability of the voting record and dealing with potential hacking in the voting system.

The ITL has demonstrated remarkable agility during this review period. Scientists in the Software Diagnostics and Conformance Testing Division show absolute mastery of short-term projects, which often have multiple external industry stakeholders with differing goals and short time frames. The

Computer Security Division has taken on many mandated initiatives following 9/11 and maintained its excellent work. Similar stories can be found in all of the divisions of ITL.

As indicated above, however, this outstanding ability is a double-edged sword. The Board is concerned about the ability of ITL to anticipate future mandates with the decline in longer-term core projects.

EFFECTIVENESS

In evaluating the effectiveness of ITL, the Board considered the extent to which each division and project linked to other communities, both internally to NIST and externally, how well they disseminated their output, and the impact of their work.

The Software Diagnostics and Conformance Testing Division has been successful in bringing a broad community of vendors together to agree on conformable standards that enable more interoperable software products. The division's testing tools for conformance to XML standards have the attention of vendors across a wide spectrum. More recently, SDCTD has been engaged with health care standards (HL7 and IEEE1073) that will enable improved interoperability across diverse health care providers.

The ANTD has been at the forefront in driving the Internet Engineering Task Force (IETF) work on securing the Domain Name System for a number of years. At various points the DNS work stalled, and the ANTD scientists devised technical advances, tools, and specifications needed to get the work going again. ANTD staff members have led the IETF editorship for five core DNS security specifications and achieved closure on their adoption, a monumental task directly aligned with the NIST mission for standardization and with the national focus on securing cyberspace. The ITL has applied an impressive approach to promoting this standard and moving it toward deployment—not just writing and analyzing, but developing deployment and measurement tools for the Internet Service Providers, users, and government agencies desiring to put the technology into practical use.

In addition to the dissemination of their work through standards bodies and technical papers, the ITL divisions have led the organization of workshops and symposiums that bring together the technical research community and vendors to consider key areas. An example is the Text Retrieval Conference (TREC), at which those doing research in information retrieval from large text collections are brought together by ITL leaders on an annual basis. These conferences have been growing, as measured by numbers of participants as well as by the challenges of the problems that they are undertaking. The Information Access Division has clearly established itself as the leader in this important area.

Examples of other gatherings coordinated by ITL include the Biometrics Consortium Conference, a conference on Building Trust and Confidence in Voting Systems, and the SPAM Technology Workshop. In these examples and many others, people needing the results come together with those doing the work under the direction of NIST leaders, which enables very rapid dissemination of results. In the rapidly moving ITL fields where much of the standardization takes place through de facto standards and vendor products, the ITL scientists have done a masterful job of encouraging interchange and agreement while avoiding the trap of endorsing individual vendor products.

Other ways in which ITL effectively disseminates its work include standard software. For example, MCSD and SED each play a role in disseminating high-quality software for standard tasks. Web-based dissemination of the NIST/SEMATECH *e-Handbook of Statistical Methods* and the future availability of the Digital Library of Mathematical Functions will provide invaluable services to the worldwide community.

Work in biometrics constitutes a major area of work in the Information Access Division. The Department of Homeland Security's US-VISIT Program—part of a continuum of security measures that begin overseas and continue through a visitor's arrival in and departure from the United States—

requires all U.S. visa applicants to have fingerprint and face biometrics captured and stored for U.S. records. In addition, the U.S. government is considering biometrics for a new federal Personal Identity Verification card. Further deployment of biometrics is expected for passports worldwide, if a U.S.-initiated effort succeeds. The Image Group of IAD has been involved in all of these projects for tasks including the following: compiling databases (the fingerprint databases now comprise 128 million fingerprints for 18 million people); designing test methodologies and performing tests on fingerprint, face, and other recognition products; testing and making recommendations on aspects of fingerprint size and quality; and involvement with standards (e.g., MINEX04—the Minutia Interoperability and Exchange test).

Through IAD's work, NIST has become a recognized authority for large-scale fingerprint databases and testing and holds a respected third-party testing role for biometrics systems. Because the U.S. government is leading the world in the required use of biometrics, and NIST benchmarks are used in decision making for U.S. government procurements, IAD has become very influential in fostering improved technologies and business progress in the biometrics industry. Funding of this work comes from congressionally appropriated biometrics initiative funds and from U.S. government agencies, including the Department of Justice, the Department of State, the Department of Homeland Security, and the Central Intelligence Agency.

RESOURCES

The ITL has been concerned for a number of years about its spatially fragmented facilities. Now there is a plan to consolidate ITL groups located at the NIST campus in Gaithersburg, Maryland. This plan will go a long way toward addressing the natural collaboration issue that is created by multiple sites. Nonetheless, some people will continue to be located at the Boulder, Colorado, campus as long as there is need to support activities there, and even on the Gaithersburg campus there will be enough physical separation that not all collaboration will happen naturally. The Board continues to urge ITL to pioneer collaborative technology, both for effective interaction and to show the way for others in overcoming the geographic distance factor.

Recently, the NIST-wide high-performance computing cluster was decommissioned. The ITL and the Physics Laboratory have taken over ownership of the system and are working with the NIST Chief Information Officer to enhance it to provide a medium-scale computational facility for use by the two laboratories. The resulting facility remains much smaller than computing facilities at other government laboratories such as the Lawrence Livermore National Laboratory and the Lawrence Berkeley National Laboratory, but the Board believes that it meets current computing needs within ITL and is sufficient to maintain the necessary level of expertise in parallel programming within ITL.

Another issue is the low bandwidth of the Internet connection between NIST and the outside world. The ANTD has initiated a pilot project with Mid-Atlantic Crossroads to link as many as 64 machines inside NIST to a regional high-speed Internet hub that will provide connections to other government agencies (e.g., National Institutes of Health), major universities in the area, and other high-speed research networks. Again, this low-budget solution seems sufficient to meet current needs of ITL, but it may need to be expanded.

There are several issues in ITL relating to human resources. With past declines in budget and the growing focus on mandated areas, there are holes in certain skill areas. Of particular concern to the Board were certain areas of statistics, mathematical optimization, and geometry. Compounding this issue of staff shortages is the projected retirement of many on the staff. There is a need to add younger staff in key skill areas both for the present and for the future health of ITL.

6

Manufacturing Engineering Laboratory

INTRODUCTION

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 (R&D), providing services, and participating in standards activities. The overall goal of MEL, consistent with that of the other NIST laboratories, is to enhance productivity, to facilitate trade, and to improve the quality of life. The MEL conducts research to anticipate future metrology and standards needs, to enable new scientific and technological advances, and to improve and refine continuously the existing measurement methods and services.

The laboratory is organized in five divisions, as shown in Appendix A:

- Precision Engineering Division (PED),
- Manufacturing Metrology Division (MMD),
- Intelligent Systems Division (ISD),
- Manufacturing Systems Integration Division (MSID), and
- Fabrication Technology Division (FTD).

The first four of these divisions are reviewed in this report. The MEL has eight focus programs that cut across divisions. These focus programs, along with the division that leads them, are listed in Table 6.1. Appendix A also presents the staffing trends for the laboratory (see Figure A.6).

MAJOR OBSERVATIONS

All MEL divisions for the most part are doing excellent technical work. For the programs evaluated, the divisions demonstrated that their activities were focused on those programs determined most essential to the mission of MEL and NIST. In some cases, as would be expected, projects had reached the

TABLE 6.1 Focus Programs and Their Lead Divisions in the Manufacturing Engineering Laboratory

Focus Program	Lead Division
Dimensional Metrology	Precision Engineering Division
Mechanical Metrology	Manufacturing Metrology Division
Nanomanufacturing	Precision Engineering Division
Intelligent Control of Mobility Systems	Intelligent Systems Division
Manufacturing Interoperability	Manufacturing Systems Integration Division
Smart Machining Systems	Manufacturing Metrology Division
Homeland and Industrial Control Security	Intelligent Systems Division
Manufacturing Metrology and Standards for the Health Care Industry	Manufacturing Systems Integration Division

stage of needing reevaluation and redirection on the basis of work being done elsewhere and shifts in priorities. Adjustments in assignments will continue to be a key activity of MEL management, to ensure that projects are properly concluded and new ones are started in a logical manner.

During the current assessment period, MEL reduced the number of its focus programs from 17 to 8. A matrix project-implementation approach within these programs has allowed much greater involvement of the appropriate technical resources to address project needs. In the past this was not as easily accomplished, since projects were divisional and often overlapping and redundant as they tried to achieve similar overall results. Crosscutting initiatives are allowing MEL to perform highly technical tasks with a much greater degree of efficiency. Many of the prior suggestions of the Board were embraced and improved upon for managing these programs. Management tools now in place include roadmaps, milestone targets tracking progress from start to finish of a project, industry feedback measures, and project prioritization and reprioritization.

Many projects were rated as outstanding by the Board. One example is Standards for the Exchange of Product Model Data (STEP). The Manufacturing Systems Integration Division has championed and implemented STEP geometric dimensioning and tolerancing (AP203 E2). Computer-aided design (CAD) vendors are testing this new standard in preparation for integrating it into their existing products. The achievement of electronic interoperability of CAD drawings has significantly benefited users. The Intelligent Systems Division has achieved recognition as a strong, international leader in intelligent control of mobility systems. The Manufacturing Metrology Division continues very impressive, internationally recognized work with its Microforce Measurement project team. There is strong evidence that this project will successfully establish worldwide the reference standard for small-force measurement. The Precision Engineering Division has received high marks from the semiconductor industry for its leadership in both critical dimension and overlay metrology. The ongoing accomplishments of the X-ray Optics Calibration Interferometer (XCALIBIR) project, which is focused on an area of significant metrology need in semiconductor manufacturing, are impressive. The project participants are highly capable, and the technical results are outstanding. The project is well connected to industrial customers who drive the development and are eagerly implementing the results.

The efforts for the deployment of technology and standards to industry are making progress. Additional attention to this goal of deployment will improve the value recognition of MEL. It will also help strengthen the success of U.S. industry, assuring that the appropriate priorities and initiatives are aligned with future needs. Projects involved in these efforts need a life-cycle plan that addresses how the project is concluded and includes a deployment plan to deliver the project results effectively to the targeted customers.

The effort undertaken by MEL to identify industry and national needs in the areas of manufacturing metrology and standards for the health care enterprise, coupled with consideration of MEL capability and expertise, is exemplary. Also, the new matrix structure employed by MEL has allowed for the rapid formation of fresh projects that address critical national needs in homeland security, with the appropriate critical resources and expertise engaged.

The Advanced Measurement Laboratory (AML) became fully functional in 2004. This state-of-the-art facility is well equipped and supported by MEL. Further refinement of equipment and processes will make this laboratory an internationally renowned operation, a center of excellence for measurement standards that will allow the United States to improve its international presence and influence on future measurement standards and practices.

Continuation of efforts on evaluating best practices and state-of-the-art technology are needed so that MEL stays apace with industry and can use industry experience to determine what and how new projects are to be developed. Data are being gathered from workshops, forums, published works, and standards committees. This information needs to be compiled, and gap analyses need to be developed to help determine needs and priorities.

TECHNICAL QUALITY AND MERIT

The overall quality of research in the Manufacturing Engineering Laboratory is high. In general, all divisions are doing excellent technical work. In many areas, the work at MEL is state of the art. The MEL appropriately emphasizes collaborative work and embraces a matrix management structure for projects to ensure that work is accomplished efficiently and rapidly, engaging the appropriate resources and minimizing redundancy. In general, the staff remains competent and motivated to fulfill roles of technical leadership.

Within the Precision Engineering Division, a move of its well-developed equipment into the new AML environment has been completed not with just equivalent performance but with enhanced performance, showing clearly that the development of AML was justified. The M48 coordinate measuring equipment move to AML was a great success, fully accomplished and now working better than before. The M48 was good to 50 nm full-volume error before and is now operating in the 20 to 30 nm range in its new laboratory in AML. One piece of equipment, the Nikon 5i, a two-dimensional pattern placement metrology tool, was not relocated, and if the opportunity presents itself it should be moved to AML as well.

Along with the move to AML, there was an effort in 2004 to bring the output capability, volume, and quality of all equipment back to pre-move levels. The PED has gone beyond this in many areas, improving its low levels of uncertainty in traceable calibrations.

The technical work of PED in length metrology is now matrix-managed under two new MEL programs: Dimensional Metrology and Nanomanufacturing. These two programs have established themselves as providing standards and measurement advancements that industry finds necessary for traceability and that are useful to enhance their own process control developments.

The PED has raised its level of excellence in cooperating with other National Metrology Institutes (NMIs). It is now taking a proactive role in driving procedural dimensional standards and reducing uncertainty levels in dimensional traceability relative to the other highly acclaimed NMIs.

Through collaboration with worldwide NMIs, industry-recognized consortia, university research, and national and international procedural standards bodies, PED has developed an accurate understanding of comparable and relevant work worldwide. It is less reactive and more preemptive now in taking a leadership position in its work, as U.S. industry needs it to do.

The PED has gone through the NIST version of an International Organization for Standardization (ISO)-17025-equivalent accreditation process, implementing the NIST Quality System for its SP250 calibrations, including an integral self-audit process. The PED was certified by NIST as compliant in October 2004, and this certification was reviewed and accepted by international NMIs (Physikalisch-Technische Bundesanstalt, National Physical Laboratory, and the Western Hemisphere NMI organization Sistema Interamericano Metrología).

During FY 2004, the Presidential Early Career Award for Scientists and Engineers was awarded to a staff member for his contributions, including realization and dissemination of the unit of force at the micro- and nanoscale. The Nanomanufacturing program in which MMD participates has been exemplary: the impact is significant, the technology challenges have been clearly identified, a detailed technical plan has been developed, and the program's team has continued to deliver accomplishments in accordance with the plan. This team has developed excellent laboratory capabilities for this program. This team is internationally recognized and has established contacts and partnerships with other national measurement laboratories in this area. There is strong evidence that the Nanomanufacturing program will successfully establish the reference standard for small-force measurement.

The MMD retains outstanding capabilities and has state-of-the-art facilities for a number of metrology services. The XCALIBIR and Microforce Measurement projects are excellent examples that include newly developed, state-of-the-art capabilities derived from ongoing technical projects. The MMD's involvement in planning for a key comparison for the optical flat is evidence that the capabilities and the new AML facilities for this program are outstanding. The geometry measuring machine offers unique measurement capability in this field.

Natural synergies exist between the previous Smart Machine Tools and Predictive Process Engineering programs. However, the Board has a concern that the scope and challenges of the Smart Machining Systems (SMS) program that has succeeded them may be too broad and might not realistically be achieved by MMD. The SMS program needs to be driven by industry and national needs and the current state of industrial practice.

The Intelligent Systems Division has facilitated the validation of metrology software tools for interoperability, working with suppliers and users of these tools on a worldwide basis. The division is receiving international recognition in this area. The ISD has taken a leadership role in homeland and industrial control security, and its involvement has gained wide recognition by other organizations and communities throughout the United States. Of significance are the development and maintenance of a set of test arenas for prove-out of robotic search-and-rescue technologies. Their arenas are transported to and replicated at many locations for demonstrations and competitions of rescue robot systems. The arenas incorporate repeatable features and challenges representing conditions found at disaster sites.

The ISD continues to support the Department of Defense's Unmanned Ground Vehicles program effectively. Enhancements to the division's previously successful demonstrations of real-time control system (RCS) controlled robotic vehicles are being implemented. The ISD team remain major contributors in the area of unmanned ground vehicle technology. Demonstrations and evaluation of these technologies by the Army Research Laboratory have identified NIST technology as making a leading contribution to the advancement of these key technologies.

Within the Manufacturing Systems Integration Division, the groups researching and influencing interoperability standards are among the best internationally. This has been demonstrated, for example, with STEP interoperability testing, the development and testing of STEP modules (in particular AP203 E2), and the assisting of vendors in implementation of the new functionality. Such activities have also been recognized through awards to staff members—for example, the PDES, Inc., award for excellence in technical management and the Boeing award for outstanding contributions to simulation modeling, a significant future tool to help assure proper design and manufacturing of advanced aircraft.

The MSID has championed the Object Management Group, the World Wide Web Consortium, and other best-practice enhancement standards to meet new interoperability requirements. A large number of informal industry consortiums articulate best-practice and industry guidelines; it is necessary for MSID to lead in the identification and enhancement of these best-practice guidelines and to ensure that they are adopted as formal standards.

In keeping with its mission, MSID is not and should not be expected to be an inventor of new technology but rather a synthesizer of known and emergent techniques to form new formally traceable standards. The distinctiveness of its proposition of formality and rigor of techniques is the key to success and a focus to be applauded. The division fulfills this role strongly and well. The MSID also does a good job of using state-of-the-art results from other groups in the national and international community to leverage its own resources.

Related to work in exchange standards, MSID aggressively seeks out the most effective partnerships to identify and address the requirements. Often the work is interdisciplinary and of distinctive value, as it is difficult to accomplish elsewhere. Some recent examples of collaboration include its work with the Automotive Industry Action Group in the area of Inventory Visibility and Interoperability, with the Department of Homeland Security in the area of simulation, and in the area of health care projects with the National Institutes of Health (NIH) and the Food and Drug Administration (FDA). Such programs will have long-term impact.

RELEVANCE

The Manufacturing Engineering Laboratory serves a vital role in ensuring that U.S. manufacturing and services will have the expertise to properly implement effective measurements and standards both within the United States and around the world. The work of MEL is relevant to the needs of customers (industry, government, and other NIST laboratories) and to the effective deployment of measurements and standards throughout the U.S. manufacturing community.

The Precision Engineering Division is demonstrating responsiveness to industry, both by leading in dimensional control capability development and by leading worldwide procedural standards developments. An example of its responsiveness is the recent emphasis on developing the scatterfield metrology work, which aligns well with the resurgent interest in nanoscale optical metrology and its contribution to the fundamental understanding of optical metrological capability essential to nanomanufacturing.

The PED is tracking the unique and specialized needs of the precision engineering industry that only a division with its own capabilities could satisfy, focusing on those needs and allowing more basic and commodity-type needs to be accomplished by ancillary and/or commercial laboratories and services. The division selects work with which it can produce the highest impact within its mission and charter. This approach adjusts PED contributions to best meet industrial customer needs (often in innovative ways) and keeps the division's equipment current in an environment of limited funding. The PED's level of effort has led to exemplary accomplishments. These include the completion of a move to AML and restoration of pre-move capacity levels, the adoption and leveraging of the new organizational structure, the accomplishment of ISO 17025 certification, and the implementation of an export-control system for the instruments in its laboratories deemed subject to such controls, while making good progress on division work and projects.

Among its activities, the Manufacturing Metrology Division develops 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 Advanced Optics Metrology Program's XCALIBIR component of the MEL Dimensional Metrology Program is focused on an area of significant metrology need in semiconductor manufacturing. The laboratory capability and technical results are outstanding.

Continued work on microforce measurement is extremely important. Its direct connection to industry activities today is limited, but it will likely achieve significant importance in the field of nanomanufacturing in the long term. The MMD role in this field of nanomanufacturing is and should be metrology services, international standards, and international measurement comparisons. The MMD's efforts will lead to the establishment of the international reference standard for small-force measurement.

A significant external challenge for the Smart Machining Systems program is the relatively low level of U.S. manufacturing presence in the high-performance machining and machining-systems equipment market. This limits the ability to form partnerships with recognized market leaders. The absence of technically and economically strong U.S.-based companies in this field provides justification for this type of work in MMD, because many U.S.-based manufacturing companies still rely on metalworking equipment and are therefore reliant on machine tool characterization methods and standards.

The Intelligent Systems Division has greatly improved its focus and industry relevance. Its manufacturing work is properly centered on standards for industry, with important research aimed at helping establish or improve future standards and technology. The ISD continues to be highly responsive to the needs of industry and other sponsors, and in all projects reviewed the division is working closely with a committed set of partners.

Higher-quality and smaller-characteristic dimensions are putting greater pressure on timely metrology, and globally dispersed operations make interoperability an even more critical requirement than in the past. By facilitating the use of various combinations of vendors' hardware and software, especially using consensus standards, the ISD is helping to foster both creativity in vendor products and, ultimately, productivity in manufacturing operations.

As a result of increased funding from other federal agencies and flat or decreasing internal funding, the fraction of ISD's work that has manufacturing as the primary focus has decreased over the past several years. There is a need for ISD and MEL in general to increase the focus of their work on core manufacturing industry problems. There remains a large potential for intelligent systems in manufacturing. It is hoped that MEL can continue to push for adding a NIST major thrust area in manufacturing. The largest single program within ISD is Intelligent Control of Mobility Systems (ICMS), which will account for about 40 percent of the operational budget in FY 2005. While there has been a small effort within the ICMS program on mobility systems in industrial applications, most of that effort has been funded by other government agencies and is directed toward military vehicles and civilian transportation. The ICMS program has clearly established itself as a technology and standards leader in this area, and it has found a far more eager customer in the U.S. Army than in industry.

The Manufacturing Systems Integration Division makes every effort to engage large, medium, and small customers in the standardization projects. The MSID also aggressively seeks out the most effective partnerships to identify and address the requirements. MSID's focus on interoperability is very good, and it will help improve U.S. manufacturing effectiveness and competitiveness. More direct funding from companies that directly benefit from the work could be pursued. As mentioned above, some recent examples of MSID collaborative efforts include the division's work with the Automotive Industry Action Group in the area of Inventory Visibility and Interoperability, with the Department of Homeland Security in the area of simulation, and in the area of health care projects with NIH and FDA.

Vendors and standards bodies are then also engaged around problems formulated by the end customers. The eventual focus is on producing formally grounded standards for interoperability. The MSID has also exhibited agility in the refocusing and redirection of expertise into NIST core program focus areas such as homeland security and health care.

The MSID management team is to be commended for evaluating opportunities and focusing effort on the areas of most likely success and impact while meeting mission objectives. The team's process includes identifying compelling industry needs and conducting the research that could lead to potentially effective standards. Resources are then managed to address the needs of a project. This research also serves to validate the longer-term strategic plan that could lead to self-integrating systems.

The STEP geometric dimensioning and tolerancing standard (AP203 E2) is being tested by CAD vendors in preparation for integrating it into existing products. It allows effective transfer of three-dimensional models into any CAD system that embraces this standard and is helping industry to communicate models without the need to make major labor-intensive conversions.

EFFECTIVENESS

The Manufacturing Engineering Laboratory is effective in delivering products and services to customers throughout the U.S. manufacturing community. For example, MMD hosts the nation's reference laboratory for the units of mass, force, vibration, and sound pressure, serving the nation by providing calibration services, developing advanced methods for metrology, developing national and international standards, and leading efforts with international standards organizations. MEL expertise and services meet critical needs of the nation's manufacturing industry and critical needs of distributed international manufacturing and commerce.

Each of the four PED groups (Large-Scale Coordinate Metrology, Engineering Metrology, Surface and Microform Metrology, and Nanoscale Metrology) is providing dissemination of its developments and results to industry in the form of industry procedural standards, NIST technical publications, Standard Reference Material (SRM) documentation, and presentations at conferences and workshops. Each has continued, and in some cases elevated, its level of participation in international and national standards bodies. Three PED groups (Large-Scale Coordinate Metrology, Engineering Metrology, and Surface and Microform Metrology) are particularly active in and have taken leadership roles in establishing the technical direction of ISO and American National Standards Institute/American Society of Mechanical Engineers (ANSI/ASME) standards; the other (Nanoscale Metrology) has been active in semiconductor industry standards groups such as Semiconductor and Materials International.

The American National Standards Institute published ANSI/ASME B89.7.3.2 and B89.7.8, two key industry standards in the area of uncertainty in dimensional measurements for which PED led the development and provided the major substance. The role of PED in this activity and its further collaboration with other ISO-member national bodies to push these improvements into ISO 14253 geometric product specification in the supplier/original equipment manufacturer business is exactly the type of world impact and leadership that U.S. industry needs NIST to practice in this area. The PED is establishing solid rapport and collaboration with the technical representatives of other ISO member countries. It is submitting alternative, more widely acceptable technical approaches that are tactfully changing the direction of ISO standardization to a direction more helpful for the long-term global and local interests of U.S. industry.

The MMD's work is disseminated through multiple means. Workshops, consortia, and standards committees continue to provide the means for disseminating many research results. Workshops are also used to identify customer needs. Many members of the technical staff are speakers at conferences and seminars. The MMD is also active in publications, presentations, and committees within numerous professional societies. These presentations, the issuance of standards, and the division's technical publications all provide evidence that MMD is serving its customers. The quantitative impact of its calibration services is demonstrated by paying customers. For example, the Mass and Force Group serves individual paying customers directly and is working with an industrial partner on implementing new, higher-resolution mass calibrations. The Machine Tool Metrology Group and the Sensor Development and Application Group also serve individual customers by providing measurement services.

The ISD publication record is excellent, and the division has shown strong leadership in a number of outside coalitions related to the areas of interoperability, smart machines, intelligent mobility systems, and industrial security. There is evidence of both near-term impact (e.g., bringing together industry sectors and assisting with new standards) and long-term impact (developing methods for better use of intelligent systems in industry and elsewhere).

In the Manufacturing Interoperability Program led by the MSID Division Chief, ISD is charged with leading the Shop Process System project, concentrating on integrating shop floor equipment. The goal of this project is to allow seamless communication within a dimensional inspection system regardless of the vendors of the individual components. The elements include the CAD data on which the inspection is based, the inspection planning software, the actual inspection machine (coordinate measuring machine) control, and the reduction and presentation of data on various platforms and with various software packages. In this project, ISD has provided several important functions in close cooperation with equipment and software suppliers. The division has helped to create interface standards for the various elements in inspection systems and has acted as a facilitator and honest broker among the various vendors. As a result, the standards that are emerging are consensus-based.

The ISD provides a physical testbed to refine and maintain these standards, using equipment loaned by many of the key industry players. This project is highly effective owing to both the technical competence of the people involved and the excellent relationships they have established with industry. It has strong support from users and suppliers globally. It has had significant impact already in providing leadership and testing support.

The MSID has built up a very strong presence in disseminating standards nationally and internationally (as with STEP, AP203 [ISO 10303-203]). The division disseminates its work through government and industry, NIST-wide, and at internal forums. Work has also been disseminated through a significantly high number of workshops, technical seminars, reports, publications, newsletters, board memberships, and consortia. Some examples are the Systems Integration for Manufacturing Applications program and the involvement with STEP development.

The MSID has had a very strong impact in STEP development. It has continued the development and testing of STEP modular development environment and modular application protocols (Automated Protocol Engines); in particular, work relating to AP203 E2 is to be commended. This new (E2) version of AP203 was modularized and updated to include several new application module sets, including Product Data Management; validation properties; three-dimensional associated text, colors, and layers; and Geometric and Dimensional Tolerancing. In particular, MSID has championed and implemented STEP geometric dimensioning and tolerancing for AP203 E2. The division has also supported the acceleration of the efforts to integrate STEP with mainstream modeling technologies including XML Schema and Unified Modeling Language. More recent MSID efforts have been initiated in the areas of systems modeling language (SYSML) and the semantic interoperability of the STEP EXPRESS language with other information modeling technologies. The MSID has also influenced enhancements by the Object Management Group, World Wide Web Consortium, and others to meet new interoperability requirements. Finally, MSID has been highly supportive of the STEP manufacturing Application Protocol developments, and in particular the development and testing of the STEP/NC AP239, and the Dimensional Inspection AP219.

RESOURCES

As of January 2005, staffing for the Manufacturing Engineering Laboratory included 200 full-time permanent positions, of which 134 were for technical professionals. There were also 25 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers. The departure of senior staff continues, and the decline in full-time permanent staff in recent years represents a significant area of concern, requiring careful management of priorities. Although the level of full-time permanent MEL staff has stabilized recently and funding has increased modestly relative to that of prior years, constraints on planning remain. As MEL management seeks to address the technical goals, objectives, and priorities of the laboratory, there are significant challenges to supporting the staff at its current level.

A strategic reevaluation of MEL's technical program portfolio over the past year has reduced the number of programs from 17 to 8 and has demonstrated MEL's ability to respond rapidly to new demands and adjust direction quickly as is required by its customers and its organization support groups. Continued application of the matrix management organizational model has proved to be a successful MEL strategy for managing increasingly collaborative activities.

Existing equipment within MEL is generally acceptable for measurement purposes. The fabrication facility is somewhat dated. Partnerships with manufacturing using the latest technology equipment would help to ensure that the divisions are staying current with the latest manufacturing practices.

The PED is selecting the work by which it can have the greatest impact while using innovation to adjust the contributions it makes in an environment of funding constraints that hamper the ability to keep equipment current. The PED leverages its staff optimally to accomplish the work that it does. There is little redundancy or depth of staff beyond the principals. Much work is accomplished by staffing second tiers through agency or temporary employees. Equipment that is less than state of the art or that is obsolete is frequently upgraded, rather than being replaced, in order to reach beyond state-of-the-art capabilities. This type of accomplishment continues to be impressive.

The MMD's difficulty in retaining talented technical professionals and in recruiting equally talented new employees is of concern. The division's success relies almost exclusively on the technical competencies of its staff, and several technically strong key personnel have left in the past few years. MMD management recognizes this challenge and is taking steps to address the issue. In particular, the strong emphasis on postdoctoral research associates is part of an effort to identify candidates for employment while also sparking their interest in a career at NIST. The MMD should remain focused on a scope of programs and projects that closely matches its available resources.

The ISD lacks adequate resources. A successful coalition with industry has brought new demands, and the division may reach the point of being unable to meet the expectations of those of its partners devoting time and money to its work.

The MSID may have less-than-sufficient staff for its defined projects. Thus, the effort in the more strategic technical projects is understandably spread out. The MSID staff have long-standing competence in formal methods in developing ontologies and tools for analysis and representations, as well as in finding deficiencies in representational methods. Core expertise has been clearly identified and maintained in the crucial area of interoperability. The MSID has also become proactive and successful in promoting staff through mechanisms such as awards.

The Manufacturing Engineering Laboratory's technical planning is very good, with the caveat that it experiences occasional diversions from the main line caused by sudden demand from its customers and lack of funds. The MEL has an excellent team of senior project managers who navigate through project-formulation options to pick the plan that will further the mission. The laboratory has implemented a review process that includes a graphical time line representation (showing planned milestones, project subgoals, and interdependencies of project activities) for major programs and activities (e.g., the move to the Advanced Measurement Laboratory).

The Board continues to encourage MEL to define a plan to predict the mix of skills that it will need in order to achieve major objectives and to chart how to maintain or obtain these skills. Anticipating events such as retirements, separations, and available new hires to the extent feasible and developing a strategy to ensure that the necessary skill mix is available for the future will increase the effectiveness of MEL's use of resources and of its programs overall.

The matrix management approach that MEL has taken for meeting its programmatic objectives is working; staff seems to have adapted well to matrix management. Laboratory management has taken steps to ensure that MEL staff is assessed by supervisors who are familiar with their project requirements and accomplishments. An example of the successful result of the new matrix management structure is the consolidation of previous large-scale engineering and surface metrology programs into a single Dimensional Metrology Program, and then using this organizational change to take advantage of economics of the scale of resources, the combination of laboratories, other space, and budgets. There seems to be an improved sense of synergy between the groups owing to this new organizational approach by MEL. There could be a downside if important, fundamental focus areas in which effort has been exerted for some time lose the attention necessary to be effective. But if the focus on fundamentals is maintained, the new organization is viewed to be an effective improvement.

7

Materials Science and Engineering Laboratory

INTRODUCTION

The mission of the Materials Science and Engineering Laboratory (MSEL) is to work with industry, standards bodies, universities, and other government laboratories to improve the nation's measurements and standards infrastructure for materials. The laboratory is organized in four divisions, as shown in Appendix A:

- Ceramics Division,
- Materials Reliability Division,
- Polymers Division, and
- Metallurgy Division.

The MSEL also includes the NIST Center for Neutron Research (NCNR). Because of the special reporting needs of the center, the findings on NCNR are presented separately in this chapter. Nevertheless, the Board interacted with the NCNR review team during this assessment cycle and found the cross-fertilization of findings to be valuable to all.

Appendix A also presents the staffing trends for the laboratory (see Figure A.7).

MAJOR OBSERVATIONS

The Board presents the following major observations with respect to the Materials Science and Engineering Laboratory:

- The MSEL has impressive programs of very high quality and technical merit as well being both relevant and effective. There are emerging programs that have high potential for future benefit.

- The MSEL staff have shown their excellence through receipt of external awards and recognition, including an impressive number of staff with membership in the National Academies.
- The MSEL fulfills its NIST mission well, and effectively disseminates information through the production of Standard Reference Materials (SRMs), Recommended Practice Guides, and databases. The laboratory uses the World Wide Web well in making information available to its customers.
- The publication record of the laboratory is exemplary. Three of its researchers are listed by Thomson-ISI as being among the most highly cited researchers in the world in materials science.
- The laboratory is recognized by industry for its contributions to technology, technology transfer, standards, and metrology.
- The new Advanced Measurement Laboratory (AML) has the potential to benefit MSEL through the use of significant new equipment such as high-resolution X-ray diffractometry.
- The NCNR facility is of enormous value to the laboratory, to NIST researchers, and to the worldwide user community. It continues to operate with a level of technical excellence that reflects very positively on the laboratory and NIST.

TECHNICAL QUALITY AND MERIT

The technical quality and merit of MSEL continue to be very high relative to the state of the art for most programs. The overall quality of the research is laudably high. To illustrate this point further, some examples of excellent research are cited below. This list is by no means all-inclusive, providing only illustrative examples. Following that is a discussion of some of the challenges and opportunities that the laboratory faces.

Examples of programs with outstanding technical quality and merit include the following:

- The program on Synchrotron Materials Science in the Ceramics Division has particular technical merit. This program includes mapping surface chemistry and molecular orientation with combinatorial Near-Edge X-ray Absorption Fine Structure spectroscopy and chemistry and structure of nanomaterials. The tools at the user facilities at both the Advanced Photon Source at Argonne National Laboratory and the National Synchrotron Light Source at the Brookhaven National Laboratory offer one-of-a-kind, NIST-like measurements. One researcher in this program was presented with the Department of Commerce Gold Medal for his pioneering development of a first-in-the-world national facility for soft X-ray absorption spectroscopy.
- There is special merit to the classical metallurgy and reliability work done in support of the World Trade Center (WTC) investigation. The work was performed collaboratively between the Metallurgy and the Materials Reliability Divisions. NIST became the lead agency in the investigation of the WTC Twin Towers collapse. Over the 2 years of this review, the NIST team has, in an effective and timely way, generated the structural data, particularly on the steel structure, needed for modeling the collapse. In particular, the team evaluated the properties of the many (more than 29) structural steels involved, at high temperatures and at high stress rates. To do so they needed to create new measurement techniques, especially concerning the yield strengths at high temperatures. The measured parameters allow meaningful modeling of the collapse of these buildings. The measurement techniques developed for the parameter determination are a permanent legacy of this project. Standardized test methods are being developed to quantitatively evaluate and compare the resistance of structural steels to high-temperature deformation and failure. This project is a demonstration of the core competencies that exist and that must be preserved in order for NIST to respond properly to this kind of failure analysis in the future.

• Within the Polymers Division, the programs involved with organic electronic materials are particularly impressive. These programs include Characterization of Porous Low-k Dielectric Constant Thin Films, Polymer Photoresists for Next-Generation Nanolithography, Organic Electronics, and Nanoimprint Lithography. Initiatives in next-generation lithography are aggressively addressing several critical issues as the surfaces and interfaces begin to dominate in nanoelectronic devices (sub-100 nm design rules). The progress in developing fundamental parameters for dissolution behavior and line-edge roughness of the image is impressive. The nanoimprint technology is but one of many contenders for future lithography, but the work is cutting edge and clearly has relevance to issues in 30 nm design rules. The vision of nanoimprint lithography as an enabler to carry out leading-edge measurement science in a variety of areas is appropriate.

• The program on Quantitative Nanomechanical Properties in the Materials Reliability Division is particularly worthy of praise. This program focuses on atomic force microscopy (AFM)-based metrology for the rapid, nondestructive measurement of mechanical properties with true nanoscale spatial resolution. It employs atomic force acoustic microscopy (AFAM) involving the vibrational resonance of an atomic force microscope cantilever when its tip is in contact with a sample. The work has matured to the point of making innovative strides in improving the data collection rates and understanding issues such as tip wear to improve the validity of data.

• The project on Mechanical Metrology for Small-Scale Structures in the Ceramics Division is impressive. This project seeks to measure the mechanical properties of industrial and biological microstructures that cannot be fabricated as bulk samples. The multifaceted project includes a combination of finite-element analysis (characterization and optimization of test configurations), specimen fabrication, and experiment (nanomechanical testing, fractography, and length/force metrology). This work represents an elegant measurement solution to important practical problems. It fits well into the NIST metrology vision. It provides a path to standards for small-scale mechanical measurements; opportunities to use this technique abound, including biomedical opportunities.

• Within the Metallurgy Division, the collective work in a number of magnetic programs is exemplary. These programs include High Coercivity FePt Alloys for Future Perpendicular Magnetic Data Storage, Electrodeposited Pt_{1-x} $(Fe,Co,Ni)_x$ Alloys, and Novel Magnetic Materials for Sensors and Ultra-High Density Data Storage. These programs pave the way for measurement metrics in the future magnetic-storage industry. Very importantly, resources have been concentrated on the development of ultrasoft magnetic thin films for very high sensitivity spin valves. Though the primary application for such high-sensitivity sensors is not obvious, it is exceedingly likely that a number of applications will be generated in a number of fields, including memory and medical applications, if such a sensor is available. This is a high-risk project with considerable payoff potential. In related work on magnetic materials, the work on ballistic magnetoresistance is commendable. The group carrying out this work has proven unambiguously that the huge magnetoresistance values reported for very small contacts were purely artifactual, resulting from mechanical alterations at the contact due to magnetostriction or particle accumulation in the presence of a field. This negative result has saved a number of companies in the hard-disk business seeking a high-sensitivity detector from pursuing a false lead.

• The work in biomaterials within the Polymers and the Materials Reliability Divisions is praiseworthy. The work in dental applications is moving from its history in dental materials to metrology at the interface between cells and scaffolds, working on standardized scaffolds and references with the American Society for Testing and Materials (ASTM). The biomaterials groups have established robust efforts in metrology at the interface between materials science and cell biology, both in the definition of relevant quantitative parameters and in the development of appropriate methodologies. Excellent progress has been made in the development of a reference scaffold, with a particular emphasis on the definition and quantification of porosity in tissue scaffolds.

- The Metrology for Nanoscale Properties: Brillouin Light Scattering program within the Materials Reliability Division has exceptional technical excellence. After many years of work on the instrumentation, this program is now ready for data collection. The Brillouin capability is unique, since all other groups in this field are focused on magnetics rather than on elastic properties, and the team is collecting very useful hardware validation of models of elasticity as a function of size. By using Brillouin scattering as the "gold" reference, the AFAM work becomes a practical secondary technique for mapping elastic properties across a nanoscale surface.

Challenges and opportunities with respect to technical quality and merit at MSEL include the following:

- For the very impressive Ceramics Division program on Mechanical Metrology for Small-Scale Structures, MSEL should find collaborators from universities that can help sustain this work.
- The work on metals and reliability for the WTC investigation is coming to a close. The skills and expertise required for that effort have continuing value, and the researchers can apply these to other projects such as pipeline failure. The Materials Reliability Division has a history of providing leadership in the areas of welding and Sharpe Impact testing, and it has many satisfied customers. However, this expertise has been on the wane; while the existing talent was crucial to the WTC investigation and work on standards for fire-resistant steels, the expertise seems to be constantly under threat of extinction. In fact, the Infrastructure program has received new funding from the Department of Transportation to look at measurements and standards for high-strength pipeline steels. While this is an effective use of the Materials Reliability Division talents, the overall program would benefit from increased focus, direction, and proactive efforts on funding.
- The scientists involved with the reliability efforts on microelectronics have done very good work. They have developed a microtensile testing facility, but it is useful primarily for calibration. This team is searching for its identity. It is doing very clever work in nanoscale reliability stress/response methodology, but it needs to connect that work to a future vision of usable metrology. It appears that the group is not well connected to its customers, and the impact of this program remains to be seen.
- In the magnetic materials research, magnetic nanoparticles are now broadly made and have been shown to have very different properties. It is not certain whether these differing properties are due to material differences or to measurement methods. There is need for Standard Reference Materials in this new field.

RELEVANCE AND EFFECTIVENESS

The MSEL scores high for choosing programs that are both relevant and effective. The programs are relevant in supporting the mission of the laboratory and of NIST. The work is effective in that the laboratory is diligent in disseminating the results of its work through many venues. The MSEL is largely very customer-focused and makes effective use of workshops and customer consortia. Illustrative examples are presented below, followed by examples of new programs that have potential for relevance and effectiveness. Finally, some comments are offered in the nature of challenges and opportunities that the laboratory faces in this arena.

Table 7.1 illustrates some of the statistical information on the output of MSEL as it pertains to relevance and effectiveness.

TABLE 7.1 Materials Science and Engineering Laboratory (MSEL): Fiscal Year 2004 Output Performance Data

Performance Criterion	Total, Measurement and Standards Laboratories (MSLs)	Total MSEL[a]	Total MSEL as Percentage of Total, MSLs
Total expenditures	$444.7 million	$47.7 million	11
Publications	1,612	502	30
Invited talks		376	
SRMs sold, total (units)	25,820	2,928	11
SRMs sold, total ($ thousand)	7,315	1,056	14
Patents pending	39	4	10
Patents issued	11	0	0
CRADAs active during FY 2004	52	5	10
Total CRADAs signed, FY 1988-2004	1,017	243	24
CRADAs (new)	16	0	0
Standards committee memberships	1,197	123	10
Standards committees chaired	138	10	7
Staff participation in standards committees	369	29	8
Guest researchers, in United States	933	207	22
Guest researchers, total	1,533	389	25

[a]Materials Science and Engineering Laboratory (excluding NIST Center for Neutron Research reactor operations).
NOTE: SRM, Standard Reference Material; CRADA, cooperative research and development agreement.

Examples of high relevance and effectiveness include the following:

- The program on Synchrotron Materials Science in the Ceramics Division used Small Business Innovative Research (SBIR) funding to connect with industry by using these funds to build instruments for novel applications. This approach is effective; the Synchrotron team could teach techniques for leveraging SBIR funding to other NIST staff.
- The Sheet Metal Forming Project is MSEL's "poster child" in the customer-service domain. Its output is highly prized by the automotive industry in particular. The forming group has been focusing on developing standard tests and data for characterizing advanced sheet material formability for the automotive community. Its most recent achievements are the introduction of a springback cup test (or the Demeri Cup Test) to the ASTM at its national meeting to explore the standardization of this test, and improvements in the new X-ray stress measuring system for the direct in situ characterization of the stress in a given direction while the sheet is under multiaxial stretching. The group has made significant progress in mapping the multiaxial stress-strain behaviors for three aluminum sheet alloys. This system enables the accurate measurement of the effect of strain paths on the evolution of the yield surface.
- Within the Polymers Division, the NIST Combinatorial Methods Center (NCMC) continues to serve as an excellent example of work with both relevance and effectiveness. This program develops combinatorial and high-throughput synthetic and measurement methodologies for the materials sciences. Key to (and a result of) its success has been the ability of the center to attract a significant industrial customer base. The center provides an important national strategic service in giving access to U.S. companies that might otherwise be unable or unwilling to make the investment needed to gain

access to combinatorial and high-throughput screening methodologies. The involvement of Food and Drug Administration (FDA) researchers in the center suggests that NCMC is also providing valuable intragovernmental service. Throughout the past 2 years, the center has continued to grow and build new devices to measure properties. The future impact of this program could be compared with that of the Phase Diagram Program, with NIST at the forefront. The program is enabling small companies with tools, methods, and a cooperative public domain approach that moves the field forward. The program encompasses the NIST missions of metrology and technology transfer.

- The Biomaterials Metrology Program in the Materials Reliability Division has been successful in its mechanical measurements. This program is commendable on many levels. It has demonstrated high-quality technical work and is an excellent example of applying NIST expertise to an important area of research that was outside a traditional area of expertise for the group. Also, the program is very well connected to the local health research community and is a best-practice example of bringing in external advisers and using external review boards to keep programs on target and to open up new conduits for technology transfer.

Examples of emerging MSEL programs with potential for high relevance and effectiveness include the following:

- The emerging thrusts in nanocalorimetry are seen as promising, with an increasing need for calorimetric measurements on very small samples. It is anticipated that the work will lead to impressive precision for measurements on such small samples that it will be relevant to U.S. industrial needs.
- The efforts on providing cantilever standards for AFM are applauded. If successful, this work will impact many U.S. technological programs and is perfectly in keeping with the NIST mission.
- Researchers previously working on lead-free materials and superconformal metal deposition are beginning to work on using these materials and processes at smaller dimensions for future interconnection technology. The Board will await the outcome from this shift of emphasis but does not offer judgment at this time.

Challenges and opportunities with respect to the relevance and effectiveness of MSEL programs include the following:

- The NIST Combinatorial Methods Center could be of even more usefulness to its customers if its resources and staff were further expanded. The NCMC can serve as a good model as MSEL expands other programs to add more direct value to the nation’s industrial base.
- The MSEL demonstrated interesting efforts in the development of gradient libraries in an effort to delineate the relationship between materials parameters and cellular responses. The Board strongly supports the thrust of the Polymers Division into the biomaterials area, but it remains concerned by the lack of vision and progress in identifying and developing relationships with a customer base. One could argue that, unlike the electronics and NCMC efforts, the industrial customer base for the output of the biological efforts is less well defined at this point. The potential industrial customers may be younger companies and the critical metrology problems less well defined, but these factors make an outreach effort all the more critical. The Board encourages the organization of workshops and conferences to reach out to the industrial base and to build collaborative programs so that MSEL can lead rather than follow the development of metrology.
- The work on nanotribology has resulted in good tools, but it is not clear to the Board what the

purpose or vision is. The investigators would benefit from a broad understanding of the project motivations. The Board finds it difficult to gauge the relevance of this work.

- The growth of semiconductor nanowires embodied some very elegant materials science with respect to gold seed particles and epitaxial ZnO growth. It is not apparent, however, that the resulting structures allow any electronic or electro-optic devices that cannot be synthesized at least as well by existing planar photolithographic techniques. The conformed electrodeposition program has historically made significant contributions to the semiconductor industry. The present interconnect project represents a positive addition to that accomplishment, but it is worth considering whether or not the superconformal project has its most valuable contributions behind it. The deposition of the ruthenium seed layer for both a barrier and a conductive layer is a significant increment, but this is a project whose future should be carefully considered before further effort is committed.
- With the generation of new materials and a proper analysis of magnetic hysteresis properties, magnetic refrigeration has been extended from the sub 1 degree K range to the tens of degrees (K) range. A space-viable magnetic refrigerator is being constructed by the National Aeronautics and Space Administration, but it is hard to see how magnetic refrigeration, with its limited caloric pumping capability, will replace conventional thermoelectric cooling devices in the foreseeable future.
- Spin-density waves have been established to exist in the ferromagnetic alloy Fe_3Al. Spin-density waves have previously been found only in antiferromagnets. This is an elegant piece of physics, but its relation to NIST's mission is not clear.
- The work in the laboratory on mass spectrometry of polymers (matrix-assisted laser desorption-ionization mass spectrometry [MALDI-MS]) has been very relevant. It is now time to consider whether the "low-hanging fruit has been picked." The laboratory may wish to consider whether the most effective use of resources is to continue these programs at their current levels.
- The premise of the work in organic electronics is valid: there is great deal of interest in this growing and technologically important field, and U.S. competitiveness is critical. There is wide variation in properties of materials prepared in different laboratories, and NIST can play an important role here in defining and developing characterization methodology and metrology, giving an edge to U.S. efforts in this field. The initial testing of materials from different leading research and development molecular electronics laboratories and their correlation to device behavior will serve as a good vehicle of technology transfer for the developed metrology. The vision for the program needs to be better defined. The collaboration with Intel provides an important avenue for MSEL technology to impact a critical industry, but it was not clear to the Board what resources (intellectual, infrastructure, financial) Intel was bringing to the table other than relevance.

The mission and management structure of the Materials Reliability Division at the Boulder campus are very unclear. This lack of clarity is affecting both morale and progress by the excellent scientists in that location. Further delay in reorganizing or naming leaders will be counterproductive.

RESOURCES

For many review cycles, the Board has advised that years of flat or declining budgets for the Materials Science and Engineering Laboratory are eroding its ability to continue the high-quality and needed work in many existing programs and potential new programs. Despite this concern, the laboratory experienced severe cuts in FY 2004, necessitating a reduction-in-force (RIF) plan. This plan was suspended pending expected increases for FY 2005. These increases were realized at least in part, and the RIF was avoided.

Nevertheless, the budget trend over a decade, whether monotonic or sawtooth, shows clearly that the laboratory had no choice but to reduce its permanent staff to compensate for budget shortfalls and inflation of staff salaries and equipment costs. An understandable response by the laboratory has been to rely more heavily on temporary staff. An increasing reliance on temporary staff erodes the core competencies of the laboratory. The Board continues to advise that this laboratory is underresourced considering its need and competency, but is concerned that this advice will fall on deaf ears.

During the 2005 review, there were fewer comments than there had been in the past from researchers on the inability to purchase needed sophisticated equipment. This may be a shock response to the aborted RIF program (researchers may be pleased merely to have their jobs). It may also reflect the equipment now available in the Advanced Measurement Laboratory.

NIST CENTER FOR NEUTRON RESEARCH

Major Observations

The NIST Center for Neutron Research has a mission to ensure the availability of neutron measurement capabilities in order to meet the needs of U.S. researchers from industry, universities, and other government agencies. The center is executing this mission well. As an overview, the Board finds the following:

- The internal science program covers an impressive range with excellent depth. Good topics are pursued with highly visible results, and many problems addressed have technological interest. Nonetheless, there must be steady critical review of the technical relevance and scientific novelty of the internal work.
- It makes no sense not to install the already-constructed 10 m small-angle neutron scattering (SANS) instrument and make it available to users through the National Science Foundation (NSF)-supported Center for High Resolution Neutron Scattering in order to relieve the large user pressure for SANS beam time.
- The integration of theory into NCNR programs is improved and should continue. The NCNR should vigorously explore collaborations with universities, government agencies, and other NIST units in order to further involve theorists.
- The reactor license renewal application was submitted to the Nuclear Regulatory Commission in a commendable way.
- There should be enhanced support for neutron reflectometry with a careful selection of appropriate problems and consideration of complementary X-ray techniques.
- There is excellent synergy between NCNR and the Spallation Neutron Source (SNS) (at the Oak Ridge National Laboratory) in instrument and program development. This exemplary cooperation might well be extended to the international arena.

Technical Quality and Merit

The number of users accommodated by NCNR and the strength of its internal research program are at outstanding levels. Quantitative measures, while only approximate, show that NCNR services users in an economical way when compared with similar national and international centers with the same mission. Excellent technical quality is evidenced by the staff's many publications in high-quality journals, with many of those publications in journals that have exceptionally high impact factors. NCNR staff members have been recognized by numerous awards both from the Department of Commerce and from external organizations. Facility users have also been honored for scientific advances enabled by the use of NCNR instruments. The organization is competitive in its efforts to bring excellent young researchers to NCNR.

The NCNR leadership is well integrated into the U.S. neutron scattering organizations, and staff members are recognized as leaders in their technical areas of neutron science. There is a particularly free exchange of information about the development of the Spallation Neutron Source at the Oak Ridge National Laboratory, and there is a clear understanding of the future synergy between the two facilities when SNS comes online.

The NCNR has in place an extensive planning process for new instruments that balances user needs with investments in new instruments and techniques. The reactor and its associated safety and security systems have in place a portfolio of timely actions designed to ensure continued levels of high availability through the entire 20-year period of relicensure.

Relevance and Effectiveness

The NCNR provides the principal source for neutron scattering experiments in the United States. As such, it is readily available and is of exceptional value to its users. Users include universities, corporations, and other governmental entities. The scope of research projects at NCNR ranges from basic sciences, to applied sciences and engineering applications, and to propriety research in support of new commercial applications. In addition to disseminating results through technical publications, the staff actively participate in summer schools, both at NCNR and elsewhere, to teach neutron scattering techniques to scientists in other fields. New Web-based applications to help experimentalists with experimental planning, data analysis, and fitting are being used effectively.

Resources

The facilities, equipment, and human resources of NCNR currently are adequate for the volume of high-quality work being carried out internally, but they are not sufficient to meet the higher volume of projects proposed by users. Thus, NCNR is staffed at or below the minimum level needed to meet its objectives. The requests for user access dramatically exceed availability, so that in some cases as few as 47 percent of the proposals can be approved, and, over the same period, the number of days approved is only 30 percent of the total number of days requested. Moreover, the lack of an adequate number of staff members limits facility development, and it also limits the professional and career development of the staffers themselves. The staff display remarkable morale and esprit de corps, but they clearly are taxed to provide the service needed. Additional permanent staffing is required to maintain and enhance the user program; any losses would harm the program.

Provisions for reactor maintenance and operation in the future have been made in a timely way. The NCNR has an exemplary safety record, and the staff understand and support the need for safe operations. Nonetheless, care must be taken to maintain continuous training and improvement and to avoid complacency. Configuration management control needs to be improved, and systems need to be developed for instruments, support facilities, and documents; these needs will probably require a dedicated champion on the staff. Coordination and new joint programs with other reactor-fuel users should be explored to enhance and ensure a stable supply of fuel for the long term.

The available equipment and facilities at NCNR are adequate at present, but additional instruments are needed to meet user demand now. Further instrument development should be done in concert with other facilities. It is significant that NCNR has managed to decommission instruments (i.e., NG-1 and the 8 m SANS) while bringing impressive new instruments online. The staff has an impressive range of ideas for instruments and sample environments that should be developed.

With respect to new instrumentation, the installation of the already-constructed 10 m SANS instrument is a high priority. Its inclusion in the Center for High Resolution Neutron Scattering will substantially relieve the large user pressure for SANS beam time. Further, there should be additional support for neutron reflectometry, which also has a substantial user base. Overarching theoretical work as well as analysis tools should be developed in parallel with instruments and with sample environments. Space issues may also become a concern, especially as the total number of instruments grows and replacement instruments increase in size and complexity.

8

Physics Laboratory

INTRODUCTION

The mission of the Physics Laboratory (PL) is to support U.S. industry by providing measurement services and research for electronic, optical, and radiation technologies. The laboratory is organized in six divisions, as shown in Appendix A:

- Atomic Physics Division,
- Electron and Optical Physics Division,
- Ionizing Radiation Division,
- Optical Technology Division,
- Time and Frequency Division, and
- Quantum Physics Division.

Appendix A also presents the staffing trends for the laboratory (see Figure A.8).

MAJOR OBSERVATIONS

• The Atomic Physics Division hosts an extremely strong theory group in atomic physics. Work of the Quantum Processes and Metrology Group continues to support groundbreaking developments in the understanding of Bose-Einstein condensation processes.

• The breadth and depth of magnetics research in the Electron and Optical Physics Division remain strong. As an example, theory work involves studies of electronic and magnetic properties of magnetic nanostructures with a focus on current-induced magnetization reversal and domain wall motion. This work, which can ultimately lead to a capability of modeling current in small structures, is at the forefront of the field; the quality and importance of the results achieved are widely recognized.

• The Ionizing Radiation Division remains the premier group in the United States for defining radiation quantities and units of exposure, for performing and/or certifying calibrations, and for recommending standards and procedures in medicine, industry, and national programs. Four accomplishments during this assessment period are considered to have notable significance: the development of self-consistent testing and evaluation protocols for radiological instrumentation and training standards for their use; the development of nuclear and explosive materials radioanalytical methods for emergency-response measurements; the development of neutron imaging to allow the tracking of water formation in proton exchange membrane (PEM)-type fuel cells; and the installation and commissioning of the high-energy computer tomography facility and the Clinac 2100 accelerator.

- The Optical Technology Division maintains a long-term core commitment to high-accuracy measurements in radiometry, photometry, and spectroradiometry. The division is commended for its continuing efforts to develop new approaches to calibration over a wide spectral range, from the far-infrared through the extreme ultraviolet (EUV).
- The Quantum Physics Division has produced a steady stream of outstanding technical accomplishments over the years. Of particular note during this assessment period is the work on Bose condensation of pairs of Fermi atoms, which is at the forefront of this rapidly moving area.
- One of the great accomplishments in the Time and Frequency Division this year has been the progress achieved on the chip-scale atomic clock project. This work supports Defense Advanced Research Projects Agency (DARPA) goals to design a miniature clock that will put enhanced communication and navigation capabilities into the hands of the battlefield soldier.
- During the assessment period there has been excellent progress in the development and advancement of optical standards, an area in which NIST excels.
- Work in the science of precision frequency standards and related standards for quantum computing is at the frontiers of knowledge. The promising results on aluminum/beryllium entangled state clocks have the potential not only to provide significant advancement in frequency accuracy but also to bring advances in fundamental areas of physics.
- A challenge faced by the Physics Laboratory is the need to retain and recruit high-profile scientists who are in demand by universities or industry.
- The Time and Frequency Division should prioritize its investments in the development of technologies and more effectively communicate why such development is relevant. For example, a customer-focused approach is needed to justify improving the accuracy of several types of clocks by order(s) of magnitude.

TECHNICAL QUALITY AND MERIT

The Quantum Processes and Metrology Group within the Atomic Physics Division is an extremely strong theory group in atomic physics, with efforts in the development of realistic theoretical models for cold atom interactions, matter waves, nanoscale devices and metrology, nano-optics, and quantum information. A particularly noteworthy example of the group's contributions is the use of theoretical understandings of Feshbach resonances to control the strength of interactions in ultracold atomic gases. This approach supports the groundbreaking work at the laboratory on molecular Bose-Einstein condensation.

The laboratory houses a highly sophisticated facility for scanning tunneling microscopy (STM) and atom manipulation focusing on low-temperature STM and structures at the atomic level. Cobalt atoms have been manipulated on the Cu (111) surface, and the detailed mechanism of the atomic mechanism of the manipulation process has been analyzed in great detail, leading to a high-profile publication in the journal *Science* (Stroscio and Celotta, 2004). The goal is atom-based metrology, using these techniques to obtain a binding energy map of the atomic surface. A very exciting but challenging long-range goal is the automated fabrication of nanoscale devices atom by atom, something akin to a semiconductor fabrication on the atomic scale. If successful, such a facility would achieve the ultimate precision in fabricating electronic devices that operate with single electrons or photons at the quantum limit. The choice of projects of this laboratory is noteworthy, setting precision standards for nanotechnology.

Magnetics projects in the laboratory are considered to be outstanding. The breadth and depth of the magnetics research in general are outstanding. As an example, PL theory work involves studies of electronic and magnetic properties of magnetic nanostructures. One focus is current-induced magnetization reversal, and another is current-induced domain wall motion. The motivation is understanding and predicting behavior as seen by scanning electron microscopy with polarization analysis (SEMPA), and in general being able to model current in small structures. This work is at the forefront of the field, and extremely well known worldwide for the quality and importance of the results that are achieved.

Other projects in this area are understanding noise in magnetic sensors (giant magnetoresistance, superconducting quantum interference device [SQUID])—in particular, finding the origin of the noise and what is needed to eliminate it. Initial results find that damping and noise are connected; the source of one is the source of another, and understanding damping in magnetic systems is critical to understanding fundamental noise sources. This part of the work is supported by NIST competence funding that involves scientists at both Gaithersburg and Boulder laboratory sites. This work is carried out by a very qualified group of people working in the area of magnetic sensors, and the project has promise. Theoretical studies are under way to calculate the large-scale electronic structure of adatom/tip interactions of STM atom moving. This work, too, couples with other work in the laboratory, and because the lead scientist is well known for his expertise in electronic structure, the project seems very well motivated.

The imaging of small structures achieved with SEMPA instrumentation is a valuable tool for the laboratory, and the results that are achieved are related to current industrial thrusts. This apparatus can detect 1,000 Fe atoms in one spot—for example, in nanoscale magnetic domains that are of crucial interest for magnetic data storage. The focus of SEMPA work is on applications involving nanometer-scale magnetic devices, such as imaging magnetic random access memory (MRAM) devices (magnetic domains, spin polarization); magnetic sensors for biology (SQUIDs); current-driven domain wall movement and spin torques (with theory work); deposition of stripe materials for ultraviolet (UV) lithography; and nonvolatile programmable logic. The issue of the spin polarization of current in nanodevices is of continuing importance, with the additional use of the SEMPA images to provide boundary conditions for micromagnetic calculations. The project has external funding from companies such as IBM and Hitachi, as well as contributions in kind from universities annually.

The Ionizing Radiation Division remains the premier group in the United States for defining radiation quantities, including the gray, the sievert, and units of exposure; performing and/or certifying calibrations; and recommending standards and procedures in medicine, industry, and national programs such as those of the U.S. Nuclear Regulatory Commission and the Department of Homeland Security (DHS). The technical competency of the group and the quality of the work in this arena are outstanding.

Four accomplishments in this area during this assessment period have notable significance: (1) the development of self-consistent testing and evaluation protocols for radiological instrumentation as well as training standards to ensure the proper use of radiation detection equipment for first responders in the case of a radiological event (an effort supporting DHS); (2) the development of nuclear and explosive materials (chemical, biological, radiological, nuclear, and explosive) radio analytical methods for emergency-response measurements (also supporting DHS); (3) the development of a high-resolution, nondestructive neutron imaging technique that allows studies of the formation and transport of water in situ in PEM-type fuel cells; and (4) enhancement of the Ionizing Radiation Division's accelerator facilities through the installation and commissioning of the high-energy computer tomography (HECT) facility and the Clinac 2100C accelerator. The neutron imaging work provides critical information for the development of fuel cells and now is the basis of collaborations with major automobile manufacturers. The HECT facility will support important missions for DHS, and the Clinac 2100C will take the medical dosimetry research and standards program of the division to a new level.

As a whole, the Optical Technology Division maintains a long-term, core commitment to high-accuracy measurements in radiometry, photometry, and spectroradiometry. The division has invested significant resources in these areas and justifiably places emphasis on maintaining the laboratory investments and careful measurement methodologies as tools for external customers in the private and government sectors. The division is commended for its continuing efforts to develop new approaches to calibration over a wide spectral range, from the far-infrared through the extreme ultraviolet.

The activities of the Physics Laboratory in optical technology are diverse, reflecting the importance of optics and optical standards in many areas of science and technology. A significant fraction of the activities are associated with maintaining critical standards for the nation. Indeed, the Optical Technology Division has the institutional responsibility for maintaining two base International System (SI) units: the unit of temperature, the kelvin, 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.

A core activity of the Optical Technology Division is the development of technical standards for industries relying on optical technologies. The division also has targeted research programs to develop optical and spectroscopic tools for gathering information on processes in the wavelength ranges required to support evolving technologies in the semiconductor, biotechnology, health science, and other industries. The research also aims to address selected fundamental problems in physics, chemistry, and engineering science that underlie these applications and in which the division can have a particularly high impact.

In view of the range of different activities in optical technology, the distinctiveness and relation to activities elsewhere must be examined using differing criteria. Within the area of optical standards, the activities within the Optical Technology Division are clearly distinctive within the United States. The facilities for maintaining standards that have been developed within the division simply do not exist elsewhere in the nation. Importantly, however, they are constantly affected by ongoing advances in optics in the broader technical community, such as the continuous improvements in tunable coherent optical sources. The natural technical point of comparison for the optical standards lies in the research carried out in national laboratories in Europe. The staff in the division are very well aware of comparable research and, indeed, engage in ongoing comparisons and cross-calibration.

Many of the other activities in optical technology, while not involving specific international optical standards, rely on highly refined measurement capabilities. Here the uniqueness of the activities results from the choice of the problems addressed as well as from the distinctiveness of the measurement capabilities themselves. In reviewing the overall program, it is clear that the activities constitute forefront research, which of necessity implies both a distinctive research agenda and broad knowledge of external activities. As an example, one could cite the array of measurement capabilities for the far-infrared or terahertz spectral region. The Optical Technology Division has outstanding measurement capabilities for this spectral region based on traditional Fourier-transform infrared techniques. It has also developed over the past years forefront capabilities for measurements using coherent radiation, including both frequency-domain and time-domain approaches. These latter coherent techniques are evolving rapidly in the external research community. The new NIST activities have immediately incorporated relevant advances from the external research community and developed what is, to the knowledge of the review Board, the best suite of measurement capabilities available in any laboratory. Similar observations apply to the distinctiveness of the research projects within the division, and their positioning vis-à-vis the external research community.

The standard of technical research in the Quantum Physics Division in collaboration with the University of Colorado is very high. Without exception, the research is very productive and explores the frontiers of the areas that are investigated.

The overall technical quality of research in the Quantum Physics Division is very high, being almost uniformly outstanding. The association of the division with faculty of the University of Colorado through JILA (Joint Institute for Laboratory Astrophysics) has resulted in a very collaborative and open environment, leading to a free exchange of ideas and a great deal of cross-fertilization between research groups.

The technical standard of research in JILA is very high. JILA fellows (personnel of both NIST and the University of Colorado) are without exception exploring the frontiers of their fields and are very productive researchers. Their work has resulted in many awards, including the Nobel Prize in physics for the observation of Bose-Einstein condensation in cold neutral atoms. This work continues through the exploration of new fundamental measurements using ultracold atoms, including an experiment to set new upper limits on the dipole moment of the electron and a new sensitive measurement of Casimir-Polder forces related to quantum interactions between atoms and surfaces. Particularly noteworthy during the current assessment period is the work on Bose condensation of pairs of Fermi atoms. The correlated motion and condensation of these pairs have proven to be distinct from similar phenomena such as the formation of Cooper pairs in superconductors or from the usual diatomic molecule formation; they exist in a previously unknown region of physics. The laboratory's work in this area is at the forefront of this rapidly moving area.

Results related to the progress in the chip-scale atomic clock obtained this year are among the significant accomplishments in the Time and Frequency Division. NIST has done an outstanding job of publicizing the technology and progress made therein, and the division is currently recognized to be the leading laboratory developing this technology. The Physics Laboratory has played a leading role in the development of chip-scale atomic clock technology. This DARPA-funded effort now involves multiple industrial and academic teams whose goal is to design a miniature atomic clock that will put enhanced communication and navigation capabilities into the hands of the modern-day battlefield soldier. The significance of the potential applications of the chip-scale atomic clock in various commercial and Department of Defense applications verifies the relevance and importance of this accomplishment.

The Physics Laboratory also recognizes that the development of high-performance clocks should not be limited to those with high stability and accuracy. Performance is defined by different criteria, based on the application; size and power, while unimportant in high-stability and high-accuracy clocks, are of paramount importance in many applications. Extension of this concept for support of future work could serve the laboratory quite well in fulfilling its mandated mission.

NIST is a leader in the development and advancement of optical standards, an area in which there has been excellent progress. The Optical Frequency Measurements Group in the Time and Frequency Division carrying out this work also strives to strengthen and expand collaboration in this area with JILA, as well as with other laboratories and universities. Progress in the calcium standard and optical comb is impressive, as is progress toward the development of the ytterbium standard.

The Ion Storage Group exemplifies investigations at the frontiers of knowledge in the science of precision frequency standards. It is acknowledged as a leader in trapped ion frequency standards and related standards for quantum computing. This group has developed and refined the techniques of entangled states not only for hyperaccurate frequency standards but for quantum computing as well. The very promising work on aluminum/beryllium entangled state clocks not only has the potential to provide significant advancement in frequency accuracy (beyond the excellent accuracy shown for the trapped mercury ion), but also brings advances in fundamental understanding of physics.

In the related area of quantum computing, NIST was recently the first to demonstrate error correction in a scalable system; NIST shares (with a laboratory in Innsbruck, Austria) the credit for the first quantum teleportation of information encoded in a massive particle (ion). This work is an excellent example of how the laboratory can transform its knowledge and technology to address emerging problems. Advances in the technology of quantum computing directly impact the ability of the United States to maintain national security through the protection of its defense information as well as by providing a capability to decrypt intelligence information from its adversaries.

Opportunities and challenges in the Physics Laboratory include those discussed below.

The diverse types of work done within the Atomic Physics Division, from cutting-edge science to the equally important but perhaps less prestigious compilation of spectral databases, demand that different metrics for success be used by management to evaluate the quality of the work performed by scientists with different assignments and expectations. The laboratory would do well to define equivalency metrics to recognize the contributions of each effort fairly.

An ongoing challenge faced by the Atomic Physics Division as well as the other divisions is the retention of high-profile scientists who are recruited strongly by top universities with “deep pockets.” Maintaining the current collegial atmosphere and opportunities for new initiatives through programs such as the competence program as well as competitive compensation will be crucial in retaining the best scientists.

The Board voices concern that a standardized electron paramagnetic resonance dosimetry technique for tooth enamel has not yet been established, in part because of differences in protocols among the three international laboratories involved in the study. One approach to solving the issues is to look at the transferability of one technique to another laboratory. Currently NIST is working with the Ukrainian Scientific Center of Nuclear Medicine to reconcile the Ukrainian protocols with those of NIST.

The NIST microwave frequency standards developed in the Time and Frequency Division are directly compared with international standards such as those in the Bureau National des Poids et Mesures. At the present time, the NIST F1 fountain standard leads the world in terms of accuracy. Nonetheless, the division needs to prioritize its investments in the development of technologies and to communicate the relevance of such pursuits effectively. For example, a more customer-focused approach is needed for justifying the effort in developing several types of clock with the target of improving accuracy by order(s) of magnitude. The division will be well served by providing answers to such questions as why this is needed, what benefits it would produce, and why the various approaches and technologies must be pursued. After good answers to these questions are provided, rather than applying efforts to making better clocks, effort should be applied toward mandates identified in those answers, and toward better time and frequency comparison techniques so that better clocks in various laboratories could be compared.

RELEVANCE

In general, the relevance of the work in all divisions of the Physics Laboratory is high to very high.

The research program in the Optical Technology Division reflects careful strategic planning to respond to NIST and national priorities. The positive results of this planning process can be seen in the close alignment of the scope of the technical agenda with clear priorities in the optical standards area, as well as the development of programs responding to NIST Strategic Focus Areas.

The existence of a vibrant and dynamic strategic planning process can be seen in the realignment of many of the activities in the Laser Applications Group. Whereas several years ago there was no work related to biological sciences or homeland security, vital programs are now in place (with extensive external collaborations) to address needs in these areas. Also, in a related vein, the frontier of optical spectroscopy of nano- and molecular-scale objects has been impressively extended.

The issue of customer focus is particularly relevant within the standards area. In this respect, a special role is filled by the Council for Optical Radiation Measurements (CORM), which evaluates national needs in optical metrology and provides feedback on the services and standards supplied by the Optical Technology Division. CORM is a body originally instituted by NIST to provide guidance and prioritization on technical needs in industry and research. The laboratory's colorimetry facility, for example, was developed in response to CORM recommendations. The effectiveness of the group could be improved by including representation and participation by the biomedical community.

The impressive level of customer satisfaction with the division can be gauged by the high level of other-agency research support. A continued high level of such external support is the ultimate test of attention to the customer.

The relevance of the work in the Time and Frequency Division is very high. This division has a variety of customers, including the lay public, the international standards community, and U.S. commerce, academia, and industry. A long-standing service that NIST provides to the American public is the dissemination of the accurate time of day to the "person on the street" via radio transmissions from the WWVB NIST radio station. Recent industry product developments in low-cost radio-controlled clocks and wristwatches have further extended the availability of this service. NIST is exploring augmenting this service with the addition of transmitters on the East Coast of the United States and in Hawaii. An Internet-based Network Time Protocol time service is similar in its ubiquity and usage by the American technical public.

EFFECTIVENESS

An extremely promising new Quantum Information Initiative spearheaded in the Physics Laboratory has generated $3 million that was distributed to seven coordinated projects spread among nine NIST divisions over three NIST laboratories. An additional $4 million is identified in the President's FY 2006 budget (OMB, 2005). Receipt of this initiative reinforces the importance of basic-research-oriented activities for the evolution and development of NIST programs.

The Optical Technology Division makes use of a variety of effective means for delivering the technical output of the division. For long-term research, the means are primarily the traditional methods of publication in the technical literature and presentations at conferences. For standards work, the division's output takes the form of calibrations of customer detectors and artifacts and making available transfer standards. Several additional forms of disseminating the technical capabilities of the division have also been implemented. Notable among these are holding specialized courses and tutorials and making available specialized software. The latter has been implemented very effectively with respect to the analysis of optical scattering data. A flexible analysis program developed in the division has been very popular, with more than 1,000 downloads. The division evidently places a healthy emphasis on publicizing and disseminating much of its technical output.

The Optical Technology Division has an excellent balance, meeting immediate needs while developing new long-term programs. This approach will keep the division at the technical forefront and ensure significant long-term impact. The standards work has an impact through a widespread chain of technology, since calibration is essential for a wide spectrum of applications. Similarly, fundamental advances in the optical characterization of materials have broad impact beyond the immediate field of optical science. Particularly noteworthy is the long-term impact and timeliness of the outstanding fundamental work on optical materials characterization for deep-UV and EUV lithography work for the semiconductor industry, where ever-more-stringent demands are being placed on the materials.

Over the years the Quantum Physics Division has produced a steady stream of outstanding technical accomplishments. The investigators and their management have been very effective in promoting these accomplishments, resulting in a number of prizes and awards, high-profile publications, and media publicity. The division has access to a pool of talented University of Colorado graduate students. Students in JILA receive an outstanding education in fundamental measurement science, and a large number of JILA Ph.D. graduates have gone on to employment within NIST. Thus, the Quantum Physics Division with JILA provides a stream of young talent for future needs of the standards and measurement laboratories.

Opportunities and challenges in the Physics Laboratory are discussed below.

An improved prioritization of effort and research approaches, examined against a clearly defined set of metrics, should be developed for time and frequency work. The relatively hands-off style of management toward these groups of activities fosters creativity, but it does not provide a focus toward goals that are well developed and well understood by all groups and group members.

The work in the Time and Frequency Division must continue to be vital and unique to NIST and the nation without becoming a collection of high-quality university-style activities. To this end, there needs to be apparent a clear connection of the division's work, now and in the future, to the stated goal "to provide the foundation of frequency measurements and civil timekeeping for our Nation" and the defined strategy "to advance measurement science and to provide time and frequency standards and measurement services to commerce, industry, and the public." Each group in the division should have a clear answer as to how it fits into the scheme, together with a wall chart that clearly delineates its roles vis-à-vis division goals and strategy. There must be continuous assessment of the research work to determine where it is heading and what needs to be done at its conclusion. Prioritization of effort and research approaches needs to be performed and examined against a clearly defined set of metrics. All research interests and opportunities clearly cannot be supported simultaneously. Different approaches need to be compared and made to compete with one another.

Continuing on the theme of clarity of purpose: parallel to the NIST Primary Time and Frequency Standards Chart showing Clock Uncertainty vs. Year for the standards NBS (National Bureau of Standards)-1 through NBS-6, NIST-7, NIST-F1, NIST-F2, and New Optical Standards, a series of charts and documentation for each standard should be generated, starting with NBS-1 and continuing through the New Optical Standards. This associated information should present the resulting research, applications, and quality-of-life improvements made possible by each particular standard. This is especially true for NIST-F1, the "ultimate Fountains," and the New Optical Standards.

RESOURCES

The proposed Quantum Institute at the University of Maryland, sponsored jointly by NIST and the university, is a very promising approach to significantly expanding the resources, facilities, and personnel studying topics central to NIST's current and future needs. There will, of course, be challenges in effectively merging the government and academic cultures. The highly successful, long-standing NIST–University of Colorado collaboration (JILA) can be a helpful reference. There are challenges in that collaboration as well, however, and it is clear that a definition of the Quantum Institute will be required that is more elaborate than the definition of JILA created a half century ago.

The Quantum Physics Division management has been very effective in retaining scientists who are at the top of their fields and are actively recruited by other universities and laboratories. It has done this by aggressively securing awards and NIST fellowships as well as high pay grades for its high-profile personnel. The past few years have seen increased cooperation between NIST and the University of Colorado in recruiting for open JILA fellow positions, within both NIST and university faculty.

The Optical Technology Division similarly highlights NIST efforts to retain quality scientists by invoking an aggressive promotion of its staff through awards and by maintaining high visibility of their accomplishments. The Board also notes that significant resources are devoted in this division toward developing the needed equipment, tools, and facilities to support customer needs.

To ensure the long-term financial health of the Physics Laboratory, the Board recommends vigilance in maintaining a good balance between outside and core funding as well as in the ratios of permanent staff to contract hires. While it may be attractive from a financial viewpoint to hire temporary staff, this practice could lead to the loss of critical scientific and technical expertise. High levels of outside funding tend to exacerbate this situation. There should be systematic and frequent examination of staff and funding source ratios to ensure long-term retention of the expertise sustaining the mission of NIST and to foster development of new technical areas.

The financial health of the Ionizing Radiation Division is much better than it was in the previous assessment period. The operating budget increased by over a factor of two, and capital equipment funding is up over 30 percent. The budget increase is due almost entirely to funds received for Department of Homeland Security work. These funds have enabled the division to maintain infrastructure and perform maintenance and repair activities for equipment. Management expressed concern about the high dependence on DHS funding and about the fate of recently hired staff, should the funding be substantially cut in the future. The management was also concerned that the newly found DHS funding would result in a reduction of NIST-derived funding—that is, diversion of NIST funding from the division to some other Physics Laboratory location or to other laboratories within NIST. There is a pressing need for 5-year planning for resources with consideration of the ratios of other agencies (OA) to Scientific and Technical Research and Services (STRS) funding.

There is probably more work to be done in the Ionizing Radiation Division than there are people available, but there does not appear to be a critical problem in this area. One issue with regard to hiring is the difficulties associated with bringing in contractors or postdoctoral fellows. A clear process does not seem to have been implemented for doing this, and if postdoctoral researchers are brought in, even into the National Research Council program, their salaries are burdened with the full NIST overhead rate. Further, much of the work done by the Radiation Interactions and Dosimetry Group is considered to be mundane, and younger people are looking for more exciting fields to pursue.

The two Titan Corporation electron linacs that will be used to support the work of the Ionizing Radiation Division have not been installed and commissioned. Problems exist with siting these accelerators, and a plan to bring them online has not been forthcoming. A concerted effort should be made by the Physics Laboratory to find space for these machines, and a plan for their installation and operation should be adopted in the short term.

JILA appears to be very stressed for space. Graduate students have “offices” within laser laboratories, for example, which is a very undesirable situation. The ability to hire into existing and future vacancies could be affected by the lack of suitable laboratory and office space for new research groups. The current use of space should be systematically reviewed with a view to increasing the efficiency of space utilization; the results of this study should then be considered in developing a plan for possible future space expansion and construction.

Issues with respect to the building facilities in the Time and Frequency Division should command attention at the highest levels of NIST. The building facilities of this division, despite recent improvements, continue to be sadly lacking in several areas. While the construction of the ion storage laboratories is a most welcome step, the overall laboratory facilities of the division are still below par compared with those of equivalent organizations elsewhere in the country or internationally. Given the environmental sensitivity of clocks and related experiments, the laboratory must be regarded as an integral part of the experimental apparatus. It is of little value to develop a clock with ultrahigh accuracy or stability when the environment cannot support this performance. The same is true for the measurement laboratory, which suffers from problems ranging from room-temperature instability to intrusive electromagnetic interference.

JILA is at its core a cooperative effort between the University of Colorado and NIST, and the self-governance by JILA fellows embodied in its Memorandum of Agreement and by-laws has been extremely effective in providing a culture that fosters innovation and groundbreaking basic science. This structure has been successful; NIST and JILA are best served by its protection and nurture. There are instances (intellectual property [IP] and emphasis in hiring, for example) in which the interests and viewpoints of the university and NIST significantly diverge. This Board reviews only the NIST part of JILA. NIST would be well served by a review Board that receives input from the whole of JILA; it could thereby consider more fully the factors that influence the continuation of this very productive university–NIST cooperative effort. The JILA environment is a key factor in attracting and retaining high-quality scientists and thus in the continued eminence of JILA's science and technology.

Intellectual property continues to be an area in which the University of Colorado and NIST seem to have conflicting interests. The problem is exacerbated by the lack of clearly communicated guidelines for NIST personnel regarding IP policy. The requirement for NIST inventions to be made widely available to the public might be facilitated by open publication of many invention disclosures, for example, but no publication exists to serve this purpose. This issue needs to be addressed by NIST as well as within JILA.

The area of biological physics is by no means confined to the Physics Laboratory or to the Quantum Physics Division. There are biological physics efforts across NIST in many other divisions—to the extent that some of the efforts are almost duplicated. Thus, there seems to be a lack of coordination of NIST-wide efforts in this area. The Quantum Physics Division scientists working on biological physics should meet regularly with other NIST biological physics scientists to coordinate efforts and ease isolation. Further, one can ask if there is a biological physics niche that is unique to NIST. NIST should identify biological problems that can be addressed with the technologies that NIST has developed.

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Appendixes

A

NIST Organizational Structure and Staffing Trends

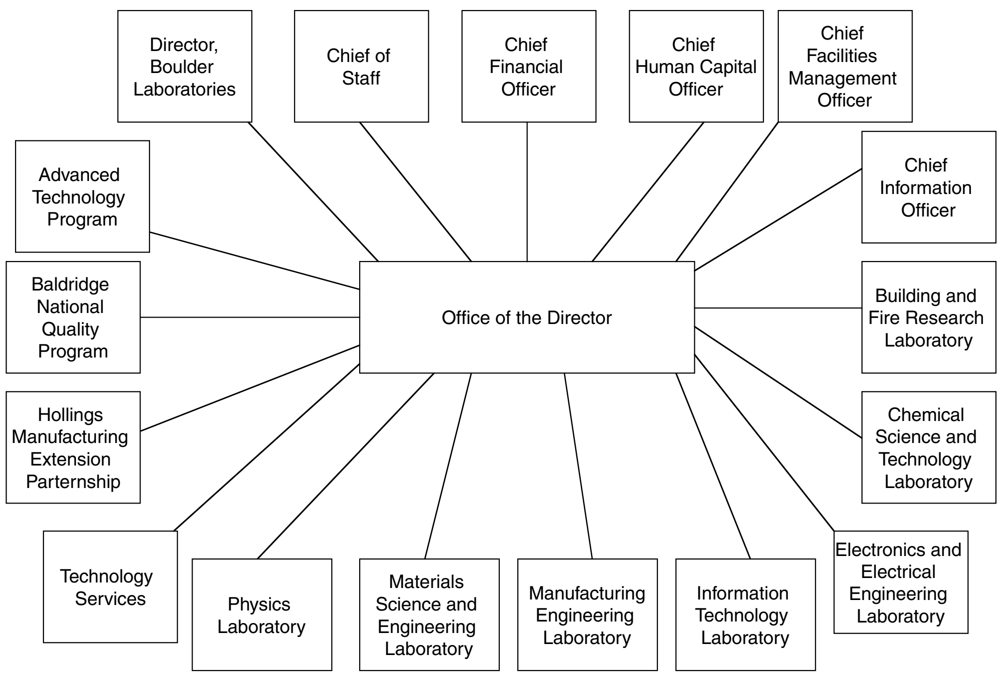

FIGURE A.1 Organizational structure of the National Institute of Standards and Technology.

The organizational structure of the National Institute of Standards and Technology (NIST) is presented graphically in Figure A.1. The organizational structure of the seven NIST Measurement and Standards Laboratories, including their divisions and the groups within each division, is outlined in the following list.

ORGANIZATIONAL STRUCTURE OF NIST LABORATORIES

- *BUILDING AND FIRE RESEARCH LABORATORY (BFRL)*

—Materials and Construction Research Division
  - Structures
  - Construction Metrology and Automation
  - Inorganic Materials
  - Polymeric Materials

—Office of Applied Economics

—Building Environment Division
  - HVAC&R Equipment Performance
  - Mechanical Systems and Controls
  - Heat Transfer and Alternative Energy Systems
  - Computer-Integrated Building Processes
  - Indoor Air Quality and Ventilation

—Fire Research Division
  - Fire Fighting Technology
  - Fire Metrology
  - Analysis and Prediction
  - Integrated Performance Assessment
  - Materials and Products

- *CHEMICAL SCIENCE AND TECHNOLOGY LABORATORY (CSTL)*

—Biotechnology Division
  - DNA Technologies
  - Bioprocess Measurements
  - Structural Biology
  - Biomolecular Materials

—Process Measurements Division
  - Fluid Flow
  - Process Sensing
  - Thermometry
  - Pressure and Vacuum
  - Thermal and Reactive Processes
  - Fluid Science

—Surface and Microanalysis Science Division
  - Microanalysis Research
  - Surface and Interface Research
  - Analytical Microscopy

—*Physical and Chemical Properties Division*
- Chemical Reference Data
- Computational Chemistry
- Experimental Properties of Fluids
- Theory and Modeling of Fluids
- Cryogenic Technologies

—*Analytical Chemistry Division*
- Spectro-chemical Methods
- Organic Analytical Methods
- Gas Metrology and Classical Methods
- Molecular Spectrometry and Microfluidic Methods
- Nuclear Methods

- *ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY (EEEL)*

—*Office of Microelectronics Programs*

—*Office of Law Enforcement Standards*

—*Quantum Electrical Metrology Division*
- Fundamental Electrical Measurements
- Applied Electrical Metrology
- Quantum Devices

—*Optoelectronics Division*
- Sources, Detectors, and Displays
- Optical Fiber and Components
- Optoelectronic Manufacturing

—*Semiconductor Electronics Division*
- Enabling Devices and ICs
- CMOS and Novel Devices
- Electronic Information
- NIST AML Nanofab

—*Electromagnetics Division*
- Radio-Frequency Electronics
- Radio-Frequency Fields
- Magnetics

- *INFORMATION TECHNOLOGY LABORATORY (ITL)*

—*Mathematical and Computational Sciences Division*
- Mathematical Modeling
- Mathematical Software
- Optimization and Computational Geometry
- Scientific Applications and Visualization

—*Information Access Division*
- Speech
- Retrieval
- Image
- Visualization and Usability
- Digital Media

—*Software Diagnostics and Conformance Testing Division*
- Software Quality
- Standards and Conformance Testing
- Interoperability

—*Advanced Network Technologies Division*
- High Speed Network Technologies
- Wireless Communications Technologies
- Internetworking Technologies

—*Statistical Engineering Division*
- Metrology Statistics and Computation
- Statistical Modeling and Analysis
- Boulder Statistics

—*Computer Security Division*
- Security Technology
- Systems and Network Security
- Security Management and Assistance
- Security Testing and Metrics

- *MANUFACTURING ENGINEERING LABORATORY (MEL)*

—*Precision Engineering Division*
- Large-Scale Coordinate Metrology
- Engineering Metrology
- Surface and Microform Metrology
- Nanoscale Metrology

—*Manufacturing Systems Integration Division*
- Systems Integration for Manufacturing Applications
- Design and Process
- Enterprise Systems
- Manufacturing Simulation and Modeling
- Manufacturing Standards Metrology

—*Manufacturing Metrology Division*
- Mass and Force
- Machine Tool Metrology

- Manufacturing Process Metrology
- Sensor Development and Application

—*Fabrication Technology Division*

—*Intelligent Systems Division*
- Machine Systems
- Control Systems
- Systems Integration
- Perception Systems
- Knowledge Systems

• *MATERIALS SCIENCE AND ENGINEERING LABORATORY (MSEL)*

—*Ceramics Division*
- Electronic and Optoelectronic Materials
- Characterization Methods
- Nanotribology
- Data Standards and Technology
- Nanomechanical Properties

—*Materials Reliability Division*
- Materials Characterization
- Process Sensing and Modeling
- Structural Materials
- Materials Evaluation

—*Polymers Division*
- Characterization and Measurement
- Electronics Materials
- Biomaterials
- Multiphase Materials
- Processing Characterization
- Multivariant Measurement Methods

—*Metallurgy Division*
- Thin Film and Nanostructure Processing
- Magnetic Materials
- Materials Performance
- Thermodynamics and Kinetics

—*NIST Center for Neutron Research*
- Reactor Operations and Engineering
- Neutron-Condensed Matter Science
- Research Facility Operations

- *PHYSICS LABORATORY (PL)*

  —*Electron and Optical Physics Division*
  - Photon Physics
  - Far UV Physics
  - Electron Physics

  —*Optical Technology Division*
  - Optical Thermometry and Spectral Methods
  - Optical Properties and Infrared Technology
  - Optical Sensor
  - Laser Applications

  —*Time and Frequency Division*
  - Ion Storage
  - Time and Frequency Services
  - Atomic Standards
  - Optical Frequency Measurements

  —*Atomic Physics Division*
  - Atomic Spectroscopy
  - Quantum Processes and Metrology
  - Plasma Radiation
  - Laser Cooling and Trapping

  —*Ionizing Radiation Division*
  - Radiation Interactions and Dosimetry
  - Neutron Interactions and Dosimetry
  - Radioactivity

  —*Quantum Physics Division*

STAFFING TRENDS, FY 1995-2004

In Chapter 1 of this report, Figure 1.1 presents aggregate data on staffing trends for the seven NIST Measurement and Standards Laboratories for the past decade. In this appendix, Figures A.2 through A.8 provide laboratory-by-laboratory staffing trends for the same period of time.

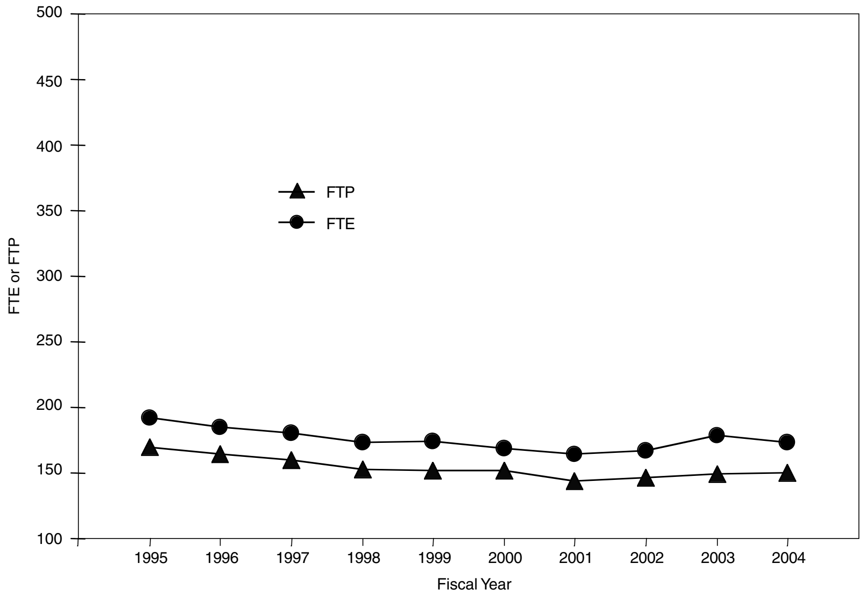

FIGURE A.2 Building and Fire Research Laboratory employment trends, 1995-2004. NOTE: FTP = full-time permanent employees; FTE = full-time-equivalent employees (FTP + other than FTP).

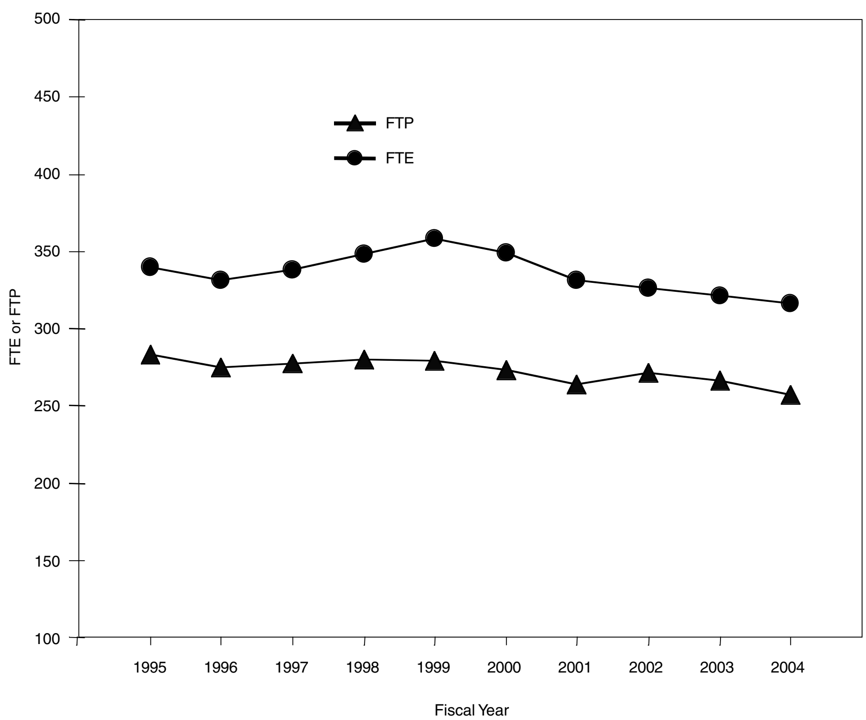

FIGURE A.3 Chemical Science and Technology Laboratory employment trends, 1995-2004. NOTE: FTP = full-time permanent employees; FTE = full-time-equivalent employees (FTP + other than FTP).

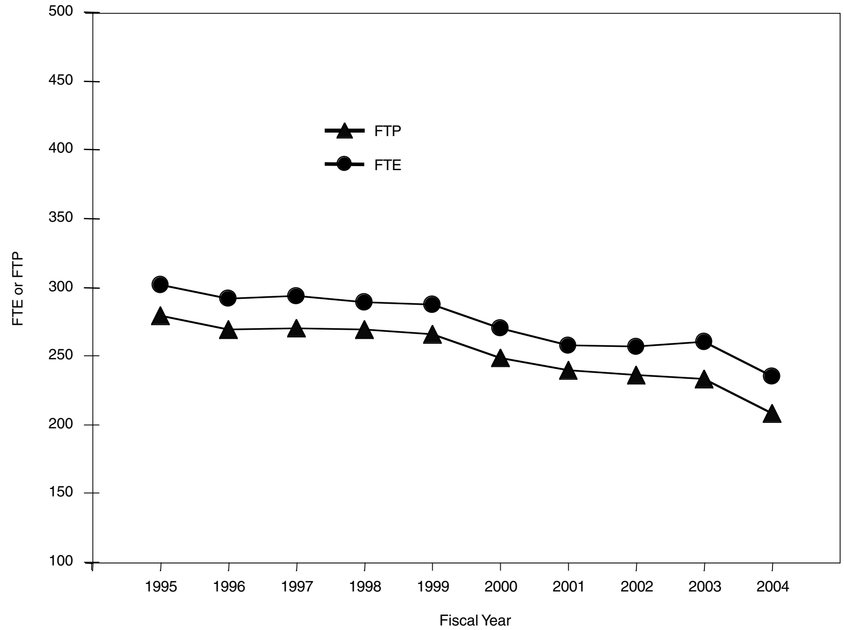

FIGURE A.4 Electronics and Electrical Engineering Laboratory employment trends, 1995-2004. NOTE: FTP = full-time permanent employees; FTE = full-time-equivalent employees (FTP + other than FTP).

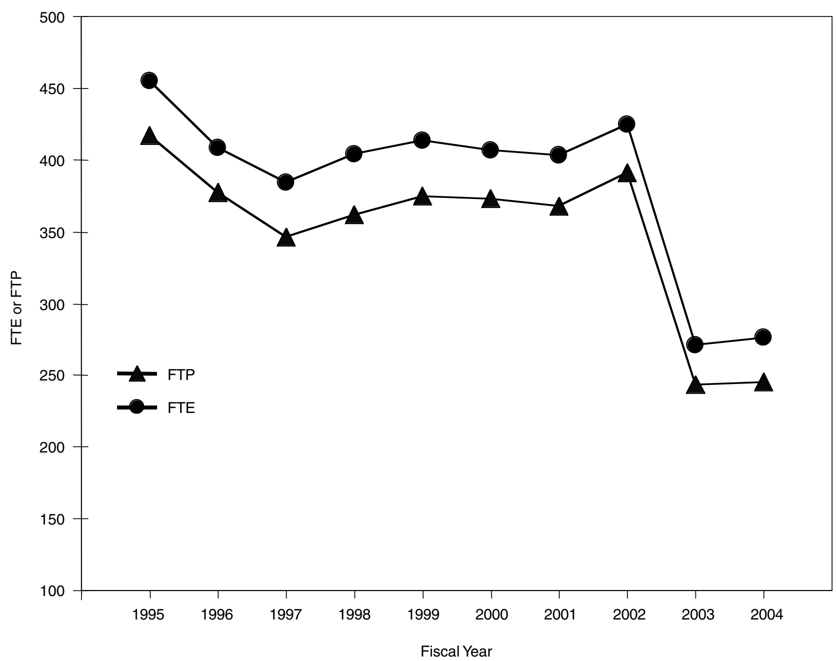

FIGURE A.5 Information Technology Laboratory (ITL) employment trends, 1995-2004. Data from FY 1995-1996 reflect combined spending for the Computer Systems Laboratory and the Computing and Applied Mathematics Laboratory. In FY 2003, Consolidated Computer System and NIST overhead-supported ITL activities were transferred to the NIST Chief Information Officer. NOTE: FTP = full-time permanent employees; FTE = full-time-equivalent employees (FTP + other than FTP).

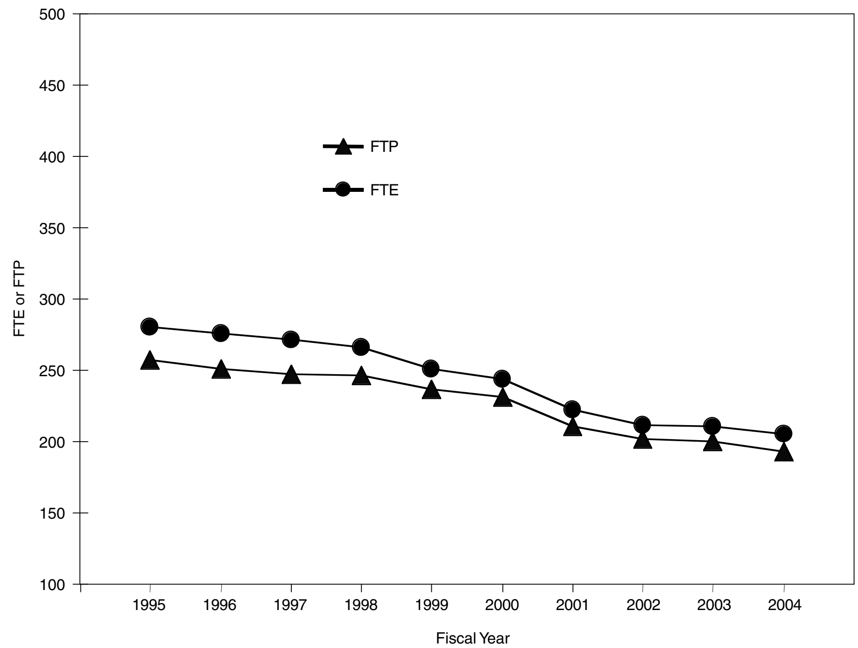

FIGURE A.6 Manufacturing Engineering Laboratory employment trends, 1995-2004. NOTE: FTP = full-time permanent employees; FTE = full-time-equivalent employees (FTP + other than FTP).

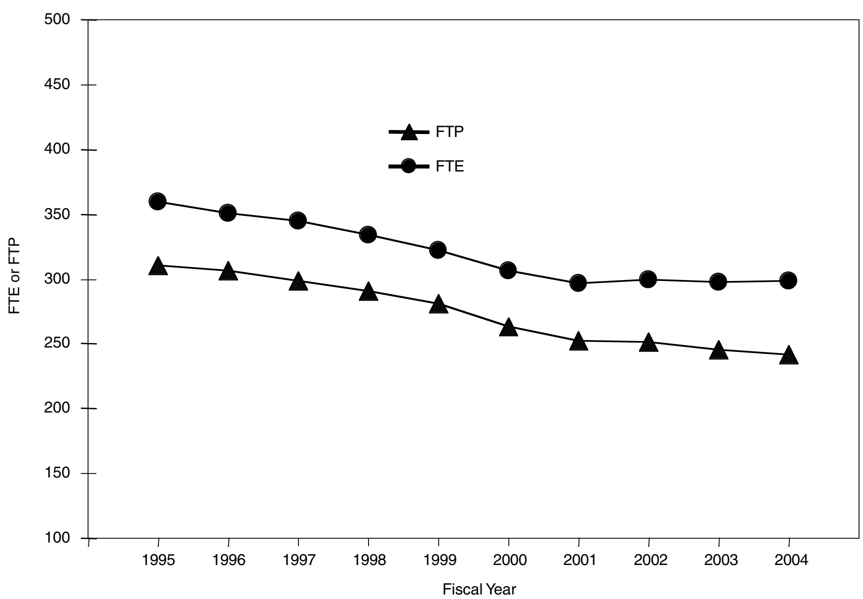

FIGURE A.7 Materials Science and Engineering Laboratory employment trends, 1995-2004. NOTE: FTP = full-time permanent employees; FTE = full-time-equivalent employees (FTP + other than FTP).

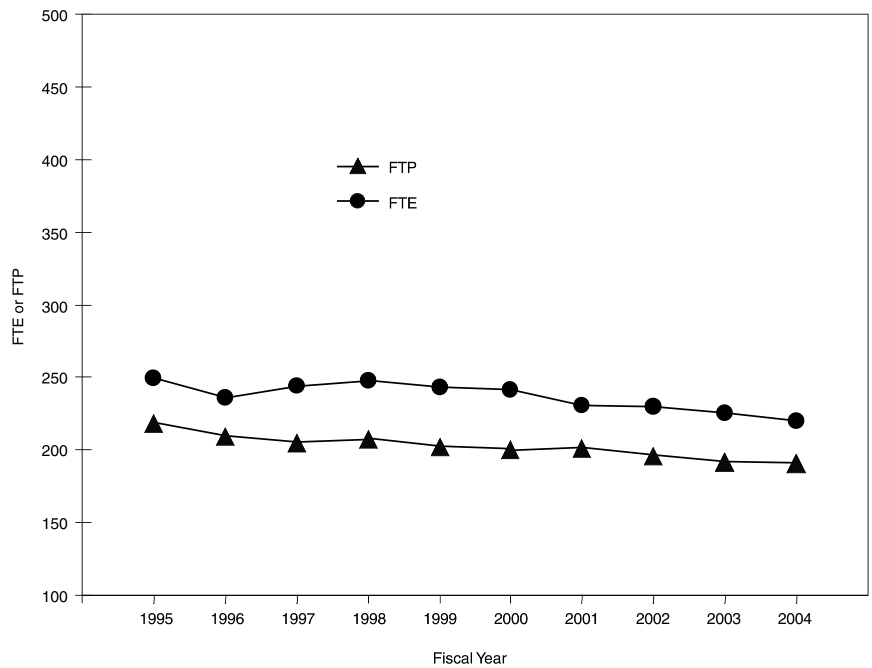

FIGURE A.8 Physics Laboratory employment trends, 1995-2004. NOTE: FTP = full-time permanent employees; FTE = full-time-equivalent employees (FTP + other than FTP).

B

Biographical Sketches of Board and Staff Members and Panel Rosters

BIOGRAPHICAL SKETCHES

Members at Large

Kenneth H. Keller (*Chair*) is Charles M. Denny, Jr., Professor of Science, Technology, and Public Policy at the University of Minnesota's Humphrey Institute of Public Affairs. Professor Keller received his Ph.D. in chemical engineering from the Johns Hopkins University. His research interests in recent years have turned to issues at the nexus of science and technology and public policy. He has held various administrative positions at the University of Minnesota. He has also served on various bodies of the National Research Council: the Committee on Future Environments for the National Institute of Standards and Technology; the Commission on Physical Sciences, Mathematics, and Applications; the Government-University-Industry Research Roundtable; the Committee to Review Proposals to the Biomedical Research Technology Transfer Partnership Awards to the State of Ohio; the Committee on Biological Threats to Agricultural Plants and Animals; and the Committee on Global Networks and Local Values. Professor Keller is a member of the National Academy of Engineering.

David C. Bonner is managing partner, Pretium Consulting Services, LLC. His previous positions include those of vice president of research and development (R&D) and chief technology officer, Cabot Corporation; global director, Rohm and Haas Company's Polymer Technology Center; senior vice president of Technology and Engineering, Westlake Group; senior vice president and chief technical officer, Premix; vice president of R&D, 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.

Oscar N. Garcia is founding and current dean of the new College of Engineering at the University of North Texas. In his previous position, he was a Distinguished NCR Chair Professor in the Computer

Science and Engineering Department at Wright State University in Dayton, Ohio. Dean Garcia has an extensive career in academia, particularly in program development, and has held two directorships at the National Science Foundation. His recent research includes topics in complexity, bioinformatics, human-computer interaction, artificial intelligence, expert systems, and software engineering. His earlier areas of research are robust speech recognition, computer architecture and parallel processing, testing of digital circuits, and arithmetic coding theory. He holds a fellow membership in the Institute of Electrical and Electronics Engineers (IEEE) and has received the Merwin Award of the Computer Society and the Emberson Award of the IEEE. He is also a fellow of the American Association for the Advancement of Science. Dean Garcia received his B.S. and M.S. degrees from the North Carolina State University and his Ph.D. from the University of Maryland. He is a past president of the IEEE Computer Society and has served on the IEEE board of directors. Dean Garcia is also a current member of the National Research Council (NRC) study on Directions of the AFOSR Mathematics and Analysis Committee. He previously served on a panel of the NRC's Army Research Laboratory Technical Assessment Board.

Anthony M. Johnson is currently director of the Center for Advanced Studies in Photonics Research at the University of Maryland in Baltimore. He had previously been chair and Distinguished Professor of Physics at the New Jersey Institute of Technology, and before that served for 14 years as a member of the technical staff in the Photonic Circuits Research Department at AT&T Bell Laboratories, with distinction. Dr. Johnson holds a B.S. degree in physics from the Polytechnic University and a Ph.D. in physics from the City University of New York. He is well recognized in the physics community for his expertise in ultrafast photophysics and nonlinear optical properties of bulk, nanostructured, and quantum-well semiconductor structures; ultrashort pulse propagation in fibers; and high-speed light-wave systems. Among the distinctions that he holds are fellowships in five professional organizations and election as president of the Optical Society in 2000. He currently serves on the U.S. National Committee for the International Commission for Optics and previously served on three NRC committees.

Mark B. Myers is an independent consultant. He retired from the Xerox Corporation at the beginning of 2000, after a 37-year career in its research and development organizations. He was the senior vice president in charge of corporate research, advanced development, systems architecture, and corporate engineering from 1992 to 2000. His responsibilities included the Corporate Research Centers, such as the Palo Alto Research Center in California. During this period, he was also a member of the senior management committee in charge of setting the strategic direction for the company. Dr. Myers recently completed an appointment as the Walter C. Bladstrom Visiting Executive Professor in Entrepreneurial Management at the Wharton School (2004-2005), where his research interests included identifying emerging markets and technologies to enable growth in new and existing companies with special emphases on technology identification and selection and product development and technology competencies. He holds a bachelor's degree from Earlham College and a doctorate from Pennsylvania State University.

Thomas A. Saponas recently retired as senior vice president and chief technology officer of Agilent Technologies as well as director of Agilent Laboratories. His responsibilities included developing the company's long-term technology strategy and overseeing the alignment of the company's objectives with its centralized R&D activities. He has more than 27 years of experience in electrical engineering, refined over the course of his career with Hewlett-Packard Company, where he began in 1972 as a design engineer in the company's Automatic Measurement Division and went on to become vice president and general manager of the Electronic Instruments Group. In 1986, he was selected to serve as a White House fellow and served as special assistant to the Secretary of the Navy for a year, on leave from Hewlett-Packard. He earned a B.S. in electrical engineering and computer science and an M.S. in electrical engineering, both from the University of Colorado.

Eugene Sevin is an independent consultant. His research interests are in nuclear and conventional weapons effects, blast-hardened facility design, and computational structural mechanics. He formerly served with the U.S. Department of Defense as deputy director, space and missile systems, and with the Defense Nuclear Agency as assistant to the deputy director (science and technology) for experimental research. Other positions that Dr. Sevin has held include professor of mechanical engineering at the Technion, Israel Institute of Technology (IIT), and head of mechanical engineering at Ben Gurion University at Negev, Israel. He earned a B.S. degree in mechanical engineering from IIT, an M.S. degree from the California Institute of Technology, and a Ph.D. in applied mechanics from IIT. He is a member of the National Academy of Engineering. He recently served as a member of the NRC Committee on Army S&T for Homeland Defense and has served on the NRC Committee on Oversight and Assessment of Blast-effects and Related Research.

Ex Officio Members

Panel for Building and Fire Research

Ross B. Corotis (*Chair*) is the Denver Business Challenge Professor in the Department of Civil, Environmental, and Architectural Engineering at the University of Colorado at Boulder. Dr. Corotis has a background in structural mechanics and stochastic vibrations; his primary research interests are in the application of probabilistic concepts to civil engineering problems. He has directed a number of research projects on subjects such as stochastic modeling of loads on structures, structural system reliability, wind characteristics for energy conversion systems, building loads, and mesoscale storm modeling. He was the founding chair of the Department of Civil Engineering at the Johns Hopkins University and dean of the College of Engineering and Applied Science at the University of Colorado. Dr. Corotis received his B.S., M.S., and Ph.D. degrees in civil engineering from the Massachusetts Institute of Technology. He is a member of the National Academy of Engineering and editor of the American Society of Civil Engineers' *Journal of Engineering Mechanics*.

Robert J. Hitchcock (*Vice Chair*) is a staff research associate in the Building Technologies Department of the Lawrence Berkeley National Laboratory. His research interests are currently focused in two areas: those of daylighting simulation and of building life-cycle information management, which involves the development of a framework for documenting and communicating performance metrics, design intent, and design rationale across the life cycle of a building project. He received his Ph.D. in civil and environmental engineering from the University of California, Berkeley. He is chair of the North American Building Services Domain Committee of the International Alliance for Interoperability.

Panel for Chemical Science and Technology

Alan Campion (*Chair*) is Dow Chemical Company Professor and University Distinguished Teaching Professor in the Department of Chemistry and Biochemistry of the University of Texas at 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 at Los Angeles. 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.

James R. Katzer (*Vice Chair*) is the manager for strategic planning and performance analysis at the Exxon Mobil Research and Engineering Company. His research interests are broad, covering several research areas performed in the Chemical Science and Technology Laboratory. Examples are his research on chemical reactions and kinetics, catalysis, and reaction engineering. Dr. Katzer has also shown leadership in the successful commercialization of catalytic processes related to pollution abatement and emissions from alternative power sources. He holds a B.S. in chemical engineering from Iowa State University and a Ph.D. in chemical engineering from the Massachusetts Institute of Technology. He is a member of the National Academy of Engineering.

Panel for Electronics and Electrical Engineering

Constance J. Chang-Hasnain (*Chair*) is a professor of electrical engineering and computer science at the University of California, Berkeley, and director of the Center for Optoelectronic Nanostructured Semiconductor Research and Technology, funded by the Defense Advanced Research Projects Agency. Her research interests include nanostructured optoelectronic materials and devices, vertical-cavity surface-emitting lasers, and microelectromechanical systems for optoelectronics, optical communications, and sensing applications. Before coming to Berkeley in 1992, she spent 5 years at Bellcore. She received a B.S. from the University of California at Davis and an M.S. and Ph.D. from the University of California, Berkeley, all in electrical engineering. She has been a Packard fellow, a Sloan fellow, and a National Young Investigator. She received the 2000 Curtis W. McGraw Research Award from the American Society for Engineering Education, the 2003 IEEE William Streifer Scientific Achievement Award, and the 2005 Gilbreth Lecturer Award from the National Academy of Engineering. Professor Chang-Hasnain is a fellow of the IEEE, and the Optical Society of America and the IEE. She was elected an honorary member of A.F. Ioffe Institute in 2005.

Robert R. Doering (*Vice Chair*) is a senior fellow in silicon technology development at Texas Instruments (TI). Currently, his primary area of responsibility at TI, where he has been working since 1980, is technology strategy. His previous positions at TI include those of manager of future-factory strategy, director of scaled-technology integration, and director of the microelectronics manufacturing science and technology program. Dr. Doering received a B.S. degree in physics from the Massachusetts Institute of Technology and a Ph.D. in physics from Michigan State University. He is co-chair of the International Technology Roadmap for Semiconductors and serves on the Corporate Associates Advisory Committee of the American Institute of Physics. He is a senior member of IEEE.

Panel for Information Technology

Albert M. Erisman (*Chair*) is the director of the Institute for Business, Technology, and Ethics and founding editor of *Ethix,* a bimonthly publication dealing with business ethics in an age of technology. He retired from the Boeing Company in 2001; there he had been director of mathematics and computing technology, leading a staff of 250 to 300 people. He was also a Boeing senior technical fellow. His own research began in mathematical algorithms and mathematical software. His management focus included the linking of research and development with business requirements and the delivery of technology for business benefit. 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. He has served as a member of several NRC committees—most recently the Committee on Information Technology Research in a Competitive World.

C. William Gear (*Vice Chair*) is president emeritus of the NEC Research Institute. Prior to joining NEC, he was head of the Department of Computer Science and professor of computer science and applied mathematics at the University of Illinois at Urbana-Champaign. His research expertise is in numerical analysis and computational software. He received a B.A. and an M.A. in mathematics from Cambridge and an M.S. and Ph.D. in mathematics from the University of Illinois at Urbana-Champaign. Dr. Gear is a member of the National Academy of Engineering and a fellow of the American Academy of Arts and Sciences, the Institute of Electrical and Electronics Engineers, the American Association for the Advancement of Science, and the Association for Computing Machinery. He served as president of the Society for Industrial and Applied Mathematics. He is past chair of the NRC Army Research Laboratory Technical Assessment Board and served on the NRC Committee on Future Environments for the National Institute of Standards and Technology.

Panel for Manufacturing Engineering

Richard A. Curless (*Chair*) is vice president of engineering for Cincinnati Machine, a subsidiary of Cincinnati Lamb located in Hebron, Kentucky. Additionally, he serves as chief technical officer for Cincinnati Lamb, a UNOVA company, headquartered in Detroit, Michigan. His responsibilities include all engineering, research, product development, and technical support services for Cincinnati Lamb. He has 40 years of experience in the machine tool industry. His previous positions include vice president of engineering for LeBlond Makino, chief engineer and manager for Cincinnati Milacron, vice president of product and business development for Cincinnati Machine, and director of global R&D for Cincinnati Lamb. He has an engineering bachelor's degree from the University of Cincinnati, an M.S. in mechanical engineering from Oklahoma State University, and an M.B.A. from Xavier University. He currently serves on various technical advisory boards and committees, including the TechSolve board of directors, the National Center for Manufacturing Sciences board of directors, and the Technology Watch Committee of the Society of Manufacturing Engineers.

Neil A. Duffie (*Vice Chair*) is a member of the Mechanical Engineering Department at the University of Wisconsin, Madison. Professor Duffie's research involves the development and optimization of several aspects of manufacturing systems. His approach centers on computer control, precision engineering computer-integrated manufacturing, micromechanisms, and robotics. He has constructed several experimental manufacturing systems that incorporate real-time, fully distributed scheduling and optimization into their control systems. He is developing theories to explain the properties and performance of these systems. Professor Duffie is associate director of the Wisconsin Center for Space Automation and Robotics.

Panel for Materials Science and Engineering

David W. Johnson, Jr. (*Chair*) retired from his position as director of the Materials Research Department at Agere Systems (previously part of Bell Laboratories) and continues as an adjunct professor of materials engineering at the Stevens Institute of Technology and as editor of the *Journal of the American Ceramic Society*. His expertise is in ceramic materials development and processing, specifically, powder preparation methods, magnetic devices, and optical fiber glasses. His research has focused on bulk and thin-film fabrication and processing of functional materials for wireless and optical communications technologies. Dr. Johnson was awarded a B.S. and Ph.D. in ceramic science from the Pennsylvania State University. He is a member of the National Academy of Engineering and a fellow and past president of the American Ceramic Society. In 2000, he received the International Ceramics Prize from the Academy of Ceramics.

Katharine G. Frase (*Vice Chair*) is director of World Wide Packaging Development for the IBM Microelectronics Division. She is responsible for all process development and design/modeling methodology for organic and ceramic chip packaging for IBM. Her research interests include mechanical properties/structural interactions in composites, high-temperature superconductors, solid electrolytes (fast ionic conductors), ceramic powder synthetic methods, and ceramic packaging. Dr. Frase received her B.A. in chemistry from Bryn Mawr College and her Ph.D. in materials science and engineering from the University of Pennsylvania. She chaired an IBM/NRC workshop on lead solder reduction actions, and in 1998 served as the packaging assurance manager for IBM worldwide.

Eric W. Kaler (*Vice Chair*) is dean of the College of Engineering and Elizabeth Inez Kelley Professor of Chemical Engineering at the University of Delaware. His research interests are in colloid and surfactant science, complex fluid dynamics, materials synthesis, and small-angle scattering. He holds a B.S. from the California Institute of Technology and a Ph.D. from the University of Minnesota, both in chemical engineering. Dr. Kaler was a Presidential Young Investigator, and he received the 1998 American Chemical Society Award in Colloid or Surface Chemistry. He is co-editor-in-chief of *Current Opinion in Colloid and Interface Science*.

Panel for Physics

Duncan T. Moore (*Chair*) is the Rudolf and Hilda Kingslake Professor of Optical Engineering and professor of biomedical engineering at the University of Rochester. From 2002 until 2004, he served as president and chief executive officer of the Infotonics Technology Center, Inc. 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, he 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. He is the founder and former president of Gradient Lens Corporation of Rochester, New York, a company that manufactures the high-quality, low-cost Hawkeye borescope. 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 adviser 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.

Arthur H. Guenther (*Vice Chair*) holds a Ph.D. in chemical physics from Rutgers University and is presently on the faculty of the University of New Mexico in the Center for High Technology Materials. His experience includes distinguished research in physics and various advisory positions in academia, as well as at three national laboratories. Dr. Guenther is a leading expert on directed-energy weaponry, including lasers, microwaves, particle beams, and pulsed-power technology. His work in nuclear weapons simulation was concerned with the response of materials to adverse environments. Dr. Guenther is the recipient of numerous awards and was science adviser to three governors of New Mexico. He is an active consultant to Department of Defense organizations, Department of Energy national laboratories, and other groups.

Staff

James P. McGee is director of the Board on Assessment of NIST Programs and director of the Army Research Laboratory Technical Assessment Board (ARLTAB), both in the Division on Engineering and Physical Sciences of the National Research Council (NRC). Since 1994, Dr. McGee has been a senior staff officer at the NRC, directing projects in the areas of systems engineering and applied psychology. These project included studies by the Committee on National Statistics' Committee on Assessing the National Science Foundation's Scientists and Engineers Statistical Data System and its Panel on Operational Testing and Evaluation of the Stryker Vehicle; the Panel on Soldier Systems for ARLTAB; the Committee on the Health and Safety Needs of Older Workers; and the Steering Committee on Differential Susceptibility of Older Persons to Environmental Hazards. He has also served as staff officer for NRC projects on Air Traffic Control Automation, Musculoskeletal Disorders and the Workplace, and the Changing Nature of Work. Prior to joining the NRC, Dr. McGee held technical and management positions in systems engineering and applied psychology at IBM, General Electric, RCA, General Dynamics, and United Technologies corporations. He received a B.A. from Princeton University and a Ph.D. from Fordham University, both in psychology, and for several years instructed postsecondary courses in applied psychology and in organizational management.

Patricia P. Paulette is a senior program officer in the NRC Division on Engineering and Physical Sciences. She has been associated with the Board on Assessment of NIST Programs for 2 years. Prior to that time, Dr. Paulette was study director for the NRC Board on Army Science and Technology, and she staffed a congressionally mandated study providing technical support to the Department of Defense in its efforts to destroy chemical-agent-containing weapons stored by the Army. Before joining the NRC, Dr. Paulette spent 20 years at the Naval Research Laboratory (NRL), where she conducted original research, provided technical support to U.S. Marine and Navy field operations, managed scientific programs, and provided technical and administrative assistance to the NRL director of research. She has also been a member of the chemistry faculty at the George Mason University in Fairfax, Virginia. Dr. Paulette's areas of technical expertise are in electrochemistry, materials, optics, and surface chemistry; she has more than 70 technical presentations and publications in these fields. Dr. Paulette holds a B.A. degree in chemistry from Barnard College and M.S. and Ph.D. degrees, also in chemistry, from the American University. She is a member of the American Chemical Society, the Electrochemical Society, the National Association of Corrosion Engineers, and Phi Kappa Phi.

PANEL ROSTERS

Panel for Building and Fire Research

Ross B. Corotis, University of Colorado, Boulder, *Chair*
Robert J. Hitchcock, Lawrence Berkeley National Laboratory, *Vice Chair*
Craig L. Beyler, Hughes Associates, Inc.
Donald B. Bivens, DuPont Fluorochemicals
Randy R. Bruegman, Fire Chief, City of Fresno
Joseph P. Colaco, CBM Engineers, Inc.
Raymond A. Dickie, Allen and Dickie Consultants
Martin Fischer, Stanford University
Delon Hampton, Delon Hampton and Associates
Kristin H. Heinemeier, Portland Energy Conservation
Susan D. Landry, Albemarle Corporation
John W. Mitchell, University of Wisconsin, Madison
Adel F. Sarofim, University of Utah
George W. Scherer, Princeton University
Jim W. Sealy, Consultant, Dallas
William Secre, Master Builders, Inc. (resigned from panel in 2004)
Frieder Seible, University of California, San Diego
E. Sarah Slaughter, MOCA Systems, Inc.

Panel for Chemical Science and Technology

Alan Campion, University of Texas, Austin, *Chair*
James R. Katzer, Exxon Mobile Research and Engineering (retired), *Vice Chair*
John Ball, U.S. Army Primary Standards Laboratory
Jeffrey B. Bindell, University of Central Florida
Ulrich Bonne, Honeywell Laboratories
Joan Brennecke, University of Notre Dame
Antonio Cantu, U.S. Secret Service
Ruby Ghosh, Michigan State University
John W. Kozarich, ActivX Biosciences, Inc.
Max G. Lagally, University of Wisconsin, Madison
R. Kenneth Marcus, Clemson University
James D. Olson, Dow Chemical Company
Athanassios Z. Panagiotopoulos, Princeton University
Gregory Stephanopoulos, Massachusetts Institute of Technology
Jennifer West, Rice University
Peter Wilding, University of Pennsylvania Medical Center
Jerome J. Workman, Jr., Thermo Electron Corporation

Panel for Electronics and Electrical Engineering

Constance J. Chang-Hasnain, University of California, Berkeley, *Chair*

Robert R. Doering, Texas Instruments, *Vice Chair*
James A. Bain, Carnegie Mellon University
Andrew A. Berlin, Intel Corporation
Peter J. Delfyett, University of Central Florida
Michael Ettenberg, Suzmar, LLC
Bruce E. Gnade, University of Texas, Dallas
Thomas J. Gramila, Ohio State University
Katherine L. Hall, Wide Net Technologies
Paul S. Ho, University of Texas, Austin (resigned from panel in 2004)
Robert C. McDonald, Metara, Inc.
G. Bruce Melson, GE Aircraft Engines
Steve Newton, Agilent Technologies, Inc.
Terry P. Orlando, Massachusetts Institute of Technology
Ghery S. Pettit, NCE, Intel Corporation
Douglas K. Rytting, Agilent Technologies, Inc. (retired)
Robert Schoelkopf, Yale University
Jonathan Scott, Agilent Technologies, Inc.
Yuan Taur, University of California, San Diego
Ronald Waxman, EDA Standards Consulting
H. Lee Willis, KEMA T&D Consulting
Barry M. Wood, National Research Council Canada

Panel for Information Technology

Albert M. Erisman, Institute for Business, Technology, and Ethics, *Chair*
C. William Gear, NEC Research Institute, Inc., *Vice Chair*
Richard Bakalar, IBM Corporation
Robert Blakley, Tivoli Systems, Inc.
John Boot, Motorola Corporation
Linda Branagan, Secondlook Consulting
Jack Brassil, Hewlett-Packard Laboratories
James A. Calvin, Texas A&M University
Susan T. Dumais, Microsoft Research
David Goodman, Brooklyn Polytechnic University
Eric Grosse, Bell Laboratories–Lucent Technologies
Cyndi Jung, Motorola Corporation
Sallie Keller-McNulty, Los Alamos National Laboratory (resigned from panel in 2004)
Stephen Kent, BBN Technologies
Isaac S. Kohane, Children's Hospital
James M. Landwehr, Avaya Labs
William A. Massey, Princeton University
Lawrence O'Gorman, Avaya Labs
David Oran, Cisco Systems, Inc.
Friedrich-Wilhelm (Fritz) Scholz, Boeing Company
Jeffrey D. Ullman, Stanford University
Stephen A. Vavasis, Cornell University

Samaradasa Weerahandi, AOL Time Warner (resigned from panel in 2004)
Mary Ellen Zurko, IBM Software Group

Panel for Manufacturing Engineering

Richard A. Curless, Cincinnati Lamb, *Chair*
Neil A. Duffie, University of Wisconsin, Madison, *Vice Chair*
Alice Agogino, University of California, Berkeley
Christopher P. Ausschnitt, IBM Microelectronics Division
Marylyn H. Bennett, International SEMATECH
Delcie R. Durham, National Science Foundation
Richard J. Furness, Ford Motor Company
Marion B. Grant, Jr., Caterpillar, Inc.
David E. Hardt, Massachusetts Institute of Technology
Steven W. Holland, General Motors R&D Center
Michael Jahadi, Lockheed Martin Aeronautics Company
Mark C. Malburg, Digital Metrology Solutions, Inc.
Carmen Pancerella, Sandia National Laboratories
Jay Ramanathan, Ohio State University
Wolfgang H. Sachse, Cornell University
Arthur C. Sanderson, Rensselaer Polytechnic Institute
Peter M. Will, Information Sciences Institute/University of Southern California
David H. Youden, Eastman Kodak Company (resigned from panel in 2004)

Panel for Materials Science and Engineering

David W. Johnson, Jr., Agere Systems, *Chair*
Katharine G. Frase, IBM Microelectronics Division, *Vice Chair*
Eric W. Kaler, University of Delaware, *Vice Chair* (until May 2005)
Ian S. Anderson, Oak Ridge National Laboratory
Edmund W. Chu, Alcoa, Inc.
Michael J. Cima, Massachusetts Institute of Technology
Kenneth L. Davis, Arizona State University
Lisa Dhar, InPhase Technologies
F.W. Gordon Fearon, Dow Corning Corporation (retired)
Zachary Fisk, University of California, Davis
Elizabeth G. Jacobs, Texas Instruments
Sylvia M. Johnson, NASA-Ames Research Center
Lee J. Magid, University of Tennessee (resigned from panel in 2004)
Omkaram Nalamasu, Rensselaer Polytechnic Institute
Thomas X. Neenan, Trine Pharmaceuticals
V. Adrian Parsegian, National Institutes of Health
Philip Pincus, University of California at Santa Barbara
Ainissa Ramirez, Yale University
Kenneth Rogers, U.S. Nuclear Regulatory Commission (retired)
Kathleen Taylor, General Motors Corporation (retired)

King-Ning Tu, University of California, Los Angeles
Mark Weaver, University of Alabama
Robert L. White, Stanford University
Barbara Wyslouzil, Ohio State University

Panel for Physics

Duncan T. Moore, University of Rochester, *Chair*
Arthur H. Guenther, University of New Mexico, *Vice Chair*
Robert H. Austin, Princeton University
Patricia A. Baisden, Lawrence Livermore National Laboratory
Robert P. Breault, Breault Research Organizations, Inc.
John H. Bruning, Corning Tropel Corporation
Albert W. Castleman, Jr., Pennsylvania State University
John F. Dicello, Johns Hopkins University
R. Michael Garvey, Symmetricom
Daniel R. Grischkowsky, Oklahoma State University
Lene Vestergaard Hau, Harvard University
Tony F. Heinz, Columbia University
Franz J. Himpsel, University of Wisconsin, Madison
Barbara Jones, IBM Almaden Research Center
Lute Maleki, Jet Propulsion Laboratory
Robert T. Menzies, Jet Propulsion Laboratory
Dennis M. Mills, Argonne National Laboratory
James M. Palmer, University of Arizona
William N. Partlo, Cymer, Inc.
David R. Schultz, Oak Ridge National Laboratory
Robert M. Shelby, IBM Corporation
William C. Stwalley, University of Connecticut
David A. Vroom, Tyco Electronics
Deborah K. Watson, University of Oklahoma

C

Acronyms and Abbreviations

ACD—Analytical Chemistry Division
AEX—Automating Equipment Information Exchange
AFAM—atomic force acoustic microscopy
AFM—atomic force microscopy
AISC—American Institute of Steel Construction
AML—Advanced Measurement Laboratory
ANTD—Advanced Network Technologies Division
ASHRAE—American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASME—American Society of Mechanical Engineers
ASTM—American Society for Testing and Materials

BACnet—Building Automation and Control Network
BD—Biotechnology Division
BED—Building Environment Division
BFRL—Building and Fire Research Laboratory

CAD—computer-aided design
CARB—Center for Advanced Research in Biotechnology
CAVP—Crypto-algorithm Validation Program
CBR—chemical, biological, and radiation
CCCBDB—Computational Chemistry Comparison and Benchmark Database
CD—compact disk; critical dimension
CFD—computational fluid dynamics
CMVP—Cryptographic Module Validation Program
CONTAM—multizone indoor-air-quality-and-ventilation-analysis computer program
CORM—Council for Optical Radiation Measurements

CPOE—computerized physician order entry
CRADA—cooperative research and development agreement
CSD—Computer Security Division
CSTL—Chemical Science and Technology Laboratory

DARPA—Defense Advanced Research Projects Agency
DHS—Department of Homeland Security
DLMF—Digital Library of Mathematical Functions
DNA—deoxyribonucleic acid
DNS—Domain Name System
DOC—Department of Commerce
DOD—Department of Defense

EEEL—Electronics and Electrical Engineering Laboratory
EHR—electronic health record
EM—electromagnetic
EOS—Electro-Optic Sampling (project); equation of state
EUV—extreme ultraviolet

FDA—Food and Drug Administration
FDS—Fire Dynamics Simulator
FEMA—Federal Emergency Management Agency
FIATECH—Fully Integrated and Automated Technology
FIPS—Federal Information Processing Standard
FRD—Fire Research Division
FTD—Fabrication Technology Division
FTE—full-time-equivalent
FTP—full-time permanent

GFP—green fluorescent protein
GRA—Guest Researcher Association

HECT—high-energy computer tomography
HfO_2—hafnium oxide
HIPAA—Health Insurance Portability and Accountability Act
HL—Health Level
HML—Hollings Marine Laboratory
HRTEM—high-resolution transmission electron microscope
HVAC/R—heating, ventilation, air conditioning, and refrigeration

IAD—Information Access Division
IAI—International Alliance for Interoperability
IBMC—Interagency Blast Mitigation Committee
ICMS—Intelligent Control of Mobility Systems
IEC—International Electrotechnical Commission
IETF—Internet Engineering Task Force

IP—intellectual property
ISD—Intelligent Systems Division
ISO—International Organization for Standardization
IT—information technology
ITL—Information Technology Laboratory
ITRS—International Technology Roadmap for Semiconductors

JILA—Joint Institute for Laboratory Astrophysics

LADAR—laser radar
LAN—local area network
LBNL—Lawrence Berkeley National Laboratory
LFL—Large Fire Laboratory
LLNL—Lawrence Livermore National Laboratory

MALDI-MS—matrix-assisted laser desorption-ionization mass spectrometry
MCRD—Materials and Construction Research Division
MCSD—Mathematical and Computational Sciences Division
MEL—Manufacturing Engineering Laboratory
MINEX 04—Minutia Interoperability Exchange Test 200
MMD—Manufacturing Metrology Division
MOS—metal-oxide semiconductor
MOSFET—metal oxide silicon field-effect transistor
MRA—Mutual Recognition Arrangement
MRAM—magnetic random access memory
MSEL—Materials Science and Engineering Laboratory
MSID—Manufacturing Systems Integration Division
MSL—Measurement and Standards Laboratory

NBS—National Bureau of Standards
NCMC—NIST Combinatorial Methods Center
NCNR—NIST Center for Neutron Research
NCSTA—National Construction Safety Team Act
NEHRP—National Earthquake Hazard Reduction Program
NIH—National Institutes of Health
NIH-ODS—Office of Dietary Supplement
NIJ—National Institute of Justice
NIST—National Institute of Standards and Technology
NMI—National Metrology Institute
NRC—National Research Council
NSF—National Science Foundation
NTP—Network Time Protocol

OA—other agencies
OAE—Office of Applied Economics
OAMG—Organic Analytical Methods Group

OLES—Office of Law Enforcement Standards
OMP—Office of Microelectronics Programs

PAT—process analytical technology
PCPD—Physical and Chemical Properties Division
PDB—Protein Data Bank
PED—Precision Engineering Division
PEM—proton exchange membrane
PL—Physics Laboratory
PMD—Process Measurements Division
PTB—Physikalisch-Technische Bundesanstalt
PVT—pressure, volume, temperature

QEM—Quantum Electrical Metrology (division)

R&D—research and development
RCS—real-time control system
REML—RF-EM-Field Metrology Laboratory
RF—radio frequency
RIF—reduction in force

S&T—science and technology
SANS—small-angle neutron scattering
SBIR—Small Business Innovative Research
SCUBA—Submillimeter Common-Use Bolometer Array
SDCTD—Software Diagnostics and Conformance Testing Division
SED—Semiconductor Electronics Division (in EEEL); Statistical Engineering Division (in ITL)
SEMATECH—Semiconductor Manufacturing Technology Consortium
SEMPA—scanning electron microscopy with polarization analysis
SFA—Strategic Focus Area
SI—International System of Units
SMS—Smart Machining System
SMSD—Surface and Microanalysis Science Division
SNS—Spallation Neutron Source
SPHERE—Simulated Photodegradation by High Energy Radiant Exposure
SQUID—superconducting quantum interference device
SRM—Standard Reference Material
STEP—Standards for the Exchange of Product Model Data
STM—scanning tunneling microscopy
STRS—Scientific and Technical Research and Services

TAS—triple axis spectroscopy
TRC—Thermodynamics Research Center
TREC—Text Retrieval Conference

UGV—unmanned ground vehicle
ULSI—ultralarge-scale integration
UV—ultraviolet
UWB—ultrawideband

VCAT—Visiting Committee on Advanced Technology
VCCTL—Virtual Cement and Concrete Testing Laboratory
VSLI—very large-scale integration

WTC—World Trade Center

XCALIBIR—X-ray Optics Calibration Interferometer
XML—extensible markup language
XML/MathML—extensible markup language/math markup language
XPS—X-ray photoelectron spectroscope