

This PDF is available at <https://nap.nationalacademies.org/29294>



An Assessment of the National Institute of Standards and Technology Physical Measurement Laboratory: Fiscal Year 2025 (2026)

DETAILS

101 pages | 8.5 x 11 | PAPERBACK

ISBN 978-0-309-60141-2 | DOI 10.17226/29294

CONTRIBUTORS

Panel on Assessment of the National Institute of Standards and Technology (NIST) Physical Measurement Laboratory (PML); Physical Sciences, Systems, and Infrastructure Program Area; Center for Advancing Science and Technology; National Academies of Sciences, Engineering, and Medicine

SUGGESTED CITATION

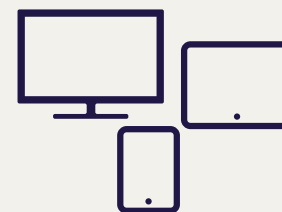
National Academies of Sciences, Engineering, and Medicine. 2026. *An Assessment of the National Institute of Standards and Technology Physical Measurement Laboratory: Fiscal Year 2025*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/29294>.

BUY THIS BOOK

FIND RELATED TITLES

Visit the National Academies Press at nap.edu and login or register to get:

- Access to free PDF downloads of thousands of publications
- 10% off the price of print publications
- Email or social media notifications of new titles related to your interests
- Special offers and discounts



All downloadable National Academies titles are free to be used for personal and/or non-commercial academic use. Users may also freely post links to our titles on this website; non-commercial academic users are encouraged to link to the version on this website rather than distribute a downloaded PDF to ensure that all users are accessing the latest authoritative version of the work. All other uses require written permission. ([Request Permission](#))

This PDF is protected by copyright and owned by the National Academy of Sciences; unless otherwise indicated, the National Academy of Sciences retains copyright to all materials in this PDF with all rights reserved.

An Assessment of the National Institute of Standards and Technology Physical Measurement Laboratory

Fiscal Year 2025

Panel on Assessment of the National Institute
of Standards and Technology (NIST) Physical
Measurement Laboratory (PML)

Physical Sciences, Systems, and
Infrastructure Program Area

Center for Advancing Science and Technology

Consensus Study Report

PREPUBLICATION COPY—Uncorrected Proofs

NATIONAL ACADEMIES PRESS 500 Fifth Street, NW Washington, DC 20001

This study was supported by a contract between the National Academy of Sciences and the National Institute of Standards and Technology (1333ND23DNB100003). Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for the project.

International Standard Book Number-13: 978-0-309-XXXXX-X

Digital Object Identifier: <https://doi.org/10.17226/29294>

This publication is available from the National Academies Press, 500 Fifth Street, NW, Keck 360, Washington, DC 20001; (800) 624-6242; <https://nap.nationalacademies.org>.

The manufacturer's authorized representative in the European Union for product safety is Authorised Rep Compliance Ltd., Ground Floor, 71 Lower Baggot Street, Dublin D02 P593 Ireland; www.arccompliance.com.

Copyright 2026 by the National Academy of Sciences. National Academies of Sciences, Engineering, and Medicine and National Academies Press and the graphical logos for each are all trademarks of the National Academy of Sciences. All rights reserved.

Printed in the United States of America.

Suggested citation: National Academies of Sciences, Engineering, and Medicine. 2026. *An Assessment of the National Institute of Standards and Technology Physical Measurement Laboratory: Fiscal Year 2025*. Washington, DC: National Academies Press. <https://doi.org/10.17226/29294>.

The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, nongovernmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

The **National Academy of Engineering** was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. Tsu-Jae Liu is president.

The **National Academy of Medicine** (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the **National Academies of Sciences, Engineering, and Medicine** to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The National Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

Learn more about the National Academies of Sciences, Engineering, and Medicine at **www.nationalacademies.org**.

Consensus Study Reports published by the National Academies of Sciences, Engineering, and Medicine document the evidence-based consensus on the study's statement of task by an authoring committee of experts. Reports typically include findings, conclusions, and recommendations based on information gathered by the committee and the committee's deliberations. Each report has been subjected to a rigorous and independent peer-review process and it represents the position of the National Academies on the statement of task.

Proceedings published by the National Academies of Sciences, Engineering, and Medicine chronicle the presentations and discussions at a workshop, symposium, or other event convened by the National Academies. The statements and opinions contained in proceedings are those of the participants and are not endorsed by other participants, the planning committee, or the National Academies.

Rapid Expert Consultations published by the National Academies of Sciences, Engineering, and Medicine are authored by subject-matter experts on narrowly focused topics that can be supported by a body of evidence. The discussions contained in rapid expert consultations are considered those of the authors and do not contain policy recommendations. Rapid expert consultations are reviewed by the institution before release.

For information about other products and activities of the National Academies, please visit www.nationalacademies.org/about/whatwedo.

PANEL ON ASSESSMENT OF THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST) PHYSICAL MEASUREMENT LABORATORY (PML)

KATE KIRBY, Chief Executive Officer (emerita), American Physical Society (retired), *Chair*
BALAKUMAR BALACHANDRAN, Distinguished University Professor, University of Maryland

CARL BLOOMFIELD, Vice President, Intertek Testing Services NA, Inc.

GEORGE BURBA, Science & Strategy Fellow, LI-COR; Global Fellow, Water for Food Global Institute; and Co-Founder, CarbonDew

YOUNG-KAI CHEN (NAE), Deputy Chief Technology Officer, Coherent Corporation

SHANYING CUI, Senior Manager, PsiQuantum

NATHALIE DE LEON, Associate Professor of Electrical and Computer Engineering, Princeton University

BENJAMIN FITZRYSLER, Technical Manager, Weights and Measures Office, Minnesota Department of Commerce

THOMAS FOLLAND, Assistant Professor, The University of Iowa

NATHAN GEMELKE, Chief Technology Strategist, QuEra Computing Inc.

IGOR GOLOVKIN, Chief Technology Officer, Prism Computational Sciences, Inc.

GUOHAN HU, Distinguished Research Scientist, IBM T.J. Watson Research Center

JUN JIAO, Professor, Portland State University

FRANK LIEBMANN, Metrology Engineer, Fluke Calibration

CHRISTOPHER MARTEL, Senior Director of Operations, Radiation Safety and Control Services, Inc.

DAVID MEDICH, Professor, Worcester Polytechnic Institute

JOHN NICHOL, Associate Professor, University of Rochester

EDWARD O'BRIEN, R&D S&E Electrical Engineer, Sandia National Laboratories

RAYMOND BENTON PAHLKA, Senior Diagnostic Medical Physicist, Texas Children's Hospital

DANIEL SCHMIDT, Manager, IBM Research

BRIJ SINGH, Electrification R&D Manager, John Deere Inc., USA

LYDIA SOHN, Professor, University of California, Berkeley

STEVEN STAHLEY, Director, Measurement Excellence, Cummins, Inc.

CHERYL XU, Professor, North Carolina State University

Study Staff

ELIZABETH ZEITLER, Director, Laboratory Assessments Board

K. JOHN HOLMES, Senior Scholar

CATHERINE WISE, Senior Program Officer

MAURA WALSH, Administrative Coordinator

PREPUBLICATION COPY—Uncorrected Proofs

Reviewers

This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, 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 thank the following individuals for their review of this report:

HASSINA BILHEUX, Oak Ridge National Laboratory
SHAWN BRITTON, NASA Langley Research Center
ANDREI FARAON, California Institute of Technology
STEPHEN KRY, The University of Texas MD Anderson Cancer Center
AN-PING LI, Oak Ridge National Laboratory
BONNIE MARLOW, The MITRE Corporation
ELISA RIEDO, New York University Tandon School of Engineering
NITIN SAMARTH, Pennsylvania State University
VICTOR VELIADIS, North Carolina State University

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report nor did they see the final draft before its release. The review of this report was overseen by **DAVID W. JOHNSON, JR. (NAE)**, Bell Laboratories (retired), and **DAVID A. WEITZ (NAS/NAE)**, Harvard University. They were responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

PREPUBLICATION COPY—Uncorrected Proofs

Contents

Preface ix

Acronyms and Abbreviations xii

Summary 1

BACKGROUND AND TASK 1
ASSESSMENT OF DIVISION TECHNICAL PROGRAMS, EXPERTISE, RESOURCES,
AND DISSEMINATION 2
OVERARCHING THEMES, CONCLUSIONS, AND RECOMMENDATIONS 7

1 Introduction 10

STATEMENT OF TASK 11
CONDUCT OF THE ASSESSMENT 13
STRUCTURE OF THE REPORT 14
REFERENCES 14

2 Microsystems and Nanotechnology 15

BACKGROUND ON THE MICROSYSTEMS AND NANOTECHNOLOGY DIVISION 15
TECHNICAL PROGRAMS 15
SCIENTIFIC EXPERTISE 18
FACILITIES, EQUIPMENT, AND HUMAN RESOURCES 19
EFFECTIVENESS OF DISSEMINATION OF PROGRAM OUTPUTS 20
CONCLUSIONS AND RECOMMENDATIONS 21
REFERENCES 23

3 Radiation Physics 24

BACKGROUND ON THE RADIATION PHYSICS DIVISION 24
TECHNICAL PROGRAMS 25
SCIENTIFIC EXPERTISE 27
FACILITIES, EQUIPMENT, AND HUMAN RESOURCES 28
EFFECTIVENESS OF DISSEMINATION OF PROGRAM OUTPUTS 29
CONCLUSIONS AND RECOMMENDATIONS 32
REFERENCES 33

4 Nanoscale Device Characterization 34

BACKGROUND ON THE NANOSCALE DEVICE CHARACTERIZATION DIVISION 34
TECHNICAL PROGRAMS 35
SCIENTIFIC EXPERTISE 37

PREPUBLICATION COPY—Uncorrected Proofs

FACILITIES, EQUIPMENT, AND HUMAN RESOURCES 38
EFFECTIVENESS OF DISSEMINATION OF PROGRAM OUTPUTS 39
CONCLUSIONS AND RECOMMENDATIONS 40
REFERENCE 41

5 Quantum Measurement 42

BACKGROUND ON THE QUANTUM MEASUREMENT DIVISION 42
TECHNICAL PROGRAMS 43
SCIENTIFIC EXPERTISE 46
FACILITIES, EQUIPMENT, AND HUMAN RESOURCES 47
EFFECTIVENESS OF DISSEMINATION OF PROGRAM OUTPUTS 48
CONCLUSIONS AND RECOMMENDATIONS 50
REFERENCES 52

6 Sensor Science 53

BACKGROUND ON THE SENSOR SCIENCE DIVISION 53
TECHNICAL PROGRAMS 54
SCIENTIFIC EXPERTISE 56
FACILITIES, EQUIPMENT, AND HUMAN RESOURCES 57
EFFECTIVENESS OF DISSEMINATION OF PROGRAM OUTPUTS 58
CONCLUSIONS AND RECOMMENDATIONS 59
REFERENCE 61

7 Conclusions and Recommendations 62

OVERARCHING CONCLUSIONS AND KEY RECOMMENDATIONS 62
DIVISION-SPECIFIC CONCLUSIONS AND RECOMMENDATIONS 65
REFERENCES 74

Appendix A Biographical Sketches of Panel 75

Appendix B Definitions of Qualitative Descriptors 89

Preface

On September 9–11, 2025, a panel selected and approved by the National Academies of Sciences, Engineering, and Medicine (National Academies) met to assess the work and accomplishments of the National Institute of Standards and Technology (NIST) Physical Measurement Laboratory (PML) based in Gaithersburg, Maryland.

It is probably underappreciated by the U.S. citizenry that the foundations of NIST (formerly the National Bureau of Standards) appear in the U.S. Constitution—giving Congress the authority to “fix the Standard of Weights and Measures”—resulting in the establishment of the oldest office within NIST (the Office of Weights and Measures). NIST’s mission has evolved since then to be the world leader in measurement science, supporting U.S. competitiveness, industrial standards, and advanced technologies. It is often said that NIST is “the national laboratory for industry.”

PML is at the core of NIST’s mission. The panel heard high quality and informative presentations of impressive work addressing the redefinition and improved accuracy of the fundamental constants, and work in disseminating SI units. PML staff pursue world-class programs involving almost all aspects of measurement science, including in quantum science, artificial intelligence, and nanotechnology, while carrying out essential calibrations supporting a large, broad customer base that includes U.S. industry, government agencies, and state metrology laboratories. This is a challenging time at NIST, with significant budget cuts, staff departures, and a hiring freeze, and leadership positions which in many cases are vacant or filled only in an “acting” capacity. In addition to these ongoing challenges, the 43-day government shutdown that occurred after our review meeting delayed PML’s calibrations for government and industry, required shutdown of scientific equipment and experiments, and suspended pay for the staff. This adds to the difficulty in recruiting and retaining talented scientists at PML with better compensation available in competing sectors (such as academia and industry).

PREPUBLICATION COPY—Uncorrected Proofs

PML staff are dealing with aging and failing laboratory infrastructure adversely affecting forefront science experiments and essential calibrations. The panel members had a front-row view of these aging infrastructure problems, with temporary HVAC systems unable to keep up with the September heat and a recent flood in at least one building preventing us from attending laboratory tours in that area. The departures of staff and the infrastructure challenges have prompted several important Key Recommendations described at the end of this report.

The panel observed the remarkable culture of the staff at NIST—a very strong work ethic, devotion to the NIST mission, and good mentoring of postdocs and younger colleagues—despite staff having to deal with so many issues that could be demoralizing. The panel wishes to thank the staff for their strong and positive attitude and for the care and effort put into preparing the materials and presentations for us. Overall, the panel was impressed with the work and expertise of the PML staff and recognizes the incredible value they bring to the nation. Therefore, any critical comments or concerns expressed in this report are to be taken in that light.

Kate Kirby, *Chair*
Panel on Assessment of the National Institute of Standards and Technology (NIST) Physical
Measurement Laboratory (PML)
March 2026

Table

B-1	Definitions of Qualitative Descriptors, 97
-----	--

Acronyms and Abbreviations

AC	alternating current
AEMG	Applied Electrical Metrology Group
AFM	atomic force microscopy
AI	artificial intelligence
BBM	Biophysical and Biomedical Measurement
Bq	becquerel
CHIPS	Creating Helpful Incentives to Produce Semiconductors
CRADA	Cooperative Research and Development Agreement
DC	direct current
DNA	deoxyribonucleic acid
DOW	Department of War
EFB	electrostatic force balance
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LCTG	Laser Cooling and Trapping Group
MND	Microsystems and Nanotechnology Division
NDCD	Nanoscale Device Characterization Division
NFM	nanostructure fabrication and measurement
NIST	National Institute of Standards and Technology
NMI	national metrology institute
PML	Physical Measurement Laboratory
POM	Photonics and Optomechanics
QMD	Quantum Measurement Division
RPD	Radiation Physics Division
SI	International System of Units
SSD	Sensor Science Division

PREPUBLICATION COPY—Uncorrected Proofs

Summary

BACKGROUND AND TASK

The National Institute of Standards and Technology (NIST) Physical Measurement Laboratory (PML) is the premier organization in the United States advancing the science of measurements that underly technologies and industries, including determinations of mass, time, frequency, temperature, electricity, and electromagnetic radiation. PML develops definitive tools and techniques for quantifying measurements, improves the precision and furthers the dissemination of the International System of Units (SI), and provides traceable calibrations for industry, government, and research. In the process, the laboratory develops expertise at the forefront of new science and technology such as in quantum science, advanced manufacturing, and health care. PML is divided into nine divisions: five based at its Gaithersburg facility, and four based at its Boulder facility. In fiscal year 2025, PML’s total budget was \$241.7 million.

The National Academies of Sciences, Engineering, and Medicine were asked by the director of NIST to assemble an expert panel to assess the work of the five PML divisions in Gaithersburg in fiscal year 2025: Microsystems and Nanotechnology, Radiation Physics, Nanoscale Device Characterization, Quantum Measurement, and Sensor Science.¹ The assessment encompasses four primary objectives: (1) assess PML’s technical programs, comparatively against world-class research, and its adequacy to reach NIST’s stated objectives; (2) assess PML’s scientific expertise comparatively to leading experts and adequacy to reach its stated objectives; (3) assess the adequacy of budget, facilities, equipment, and human resources; and (4) assess the effectiveness of PML’s dissemination of its program outputs, in terms of direction toward stakeholder needs, effectiveness of methods, and monitoring of stakeholder use and impact. The full statement of task is included in the introductory chapter of this report. The

¹ Complementary fiscal year 2025 National Academies of Sciences, Engineering, and Medicine assessments are available of NIST’s Center for Neutron Research and three divisions of the Communications Technology Laboratory.

expert panel structured its review by division, and developed overarching conclusions and key recommendations, as well as division-specific conclusions and recommendations.

ASSESSMENT OF DIVISION TECHNICAL PROGRAMS, EXPERTISE, RESOURCES, AND DISSEMINATION

Microsystems and Nanotechnology Division

The Microsystems and Nanotechnology Division (MND) advances device fabrication and measurement at the sub-micron or less length scale, with the dual aim of improving technology as well as measurement science. Programmatic thrusts focus on Nanostructure Fabrication and Measurement, Photonics and Optomechanics, and Biophysical and Biomedical Measurement. The MND is highly successful in its technical programs, such as in developing a standard for optical and electron-beam microscopy tools, collaborating to develop on-chip light generation with modulators toward optical clocks, mass sensing, and device metrology, and developing on-chip-scale flow rate sensors and traceable metrology for flow cytometry and micro biomembrane applications. The division is well connected and responsive to industry and government stakeholders who use its standards, calibrations, and technological advances.

Scientific expertise in the MND mirrors and underlies its successful technical programs. On the whole, division staff produce high-quality research publications, hold leadership positions within industry or international standards working groups, and maintain strong relationships with many major stakeholders (though increased engagement with stakeholders in rapidly evolving technology areas could be beneficial). Recent staff departures have left the group understaffed, and maintaining and enhancing expertise in semiconductor metrology will be important for continuing to meet stakeholder needs.

The MND subpanel's conclusions and recommendations are presented in Chapter 2. The subpanel recommended that PML group leaders participate in leadership opportunities within their research communities, staff and associates to attend conferences and working groups, and engage earlier with industry; PML leadership prioritize support for the nanofabrication facility, provide clear pathways for professional development and advancement, and consider tracking additional metrics for dissemination and impact.

Radiation Physics Division

The Radiation Physics Division (RPD) develops, maintains, and disseminates standards for measuring ionizing radiation. Such standards are critical for radiation protection, treating and diagnosing disease with radiation, and supporting nuclear energy, homeland security, and environmental monitoring. The RPD contains three groups: Dosimetry, Neutron Physics, and Radioactivity. The division is an international leader in radiation metrology, and recent accomplishments include activity calibration of liquid sources at the level of one Becquerel (Bq, one decay per second), development of new neutron imaging techniques, and standards setting for alpha emitters for radiation cancer therapy. The RPD's work enables the radiation treatment of about 1 million cancer patients, screening of about 40 million mammogram patients, protection of 4 million radiation workers, and public safety by detecting and quantifying radioactive contaminant releases.

The division has world-class expertise in radiation measurement science, and its staff are global leaders in realizing and disseminating key SI units: the Bq, gray, and sievert. Their publication output is consistent with peer academic researchers in the field. Departures of key personnel have hampered several mission-critical projects, such as instrument calibration. Another key challenge for the division is the poor quality of the facilities in which the laboratories are based. For example, the division's calibration facilities have unsafe flooring and electrical supply, outdated electrometers, and laboratories with insufficient temperature and humidity controls. Despite the challenges posed by the facilities, the RPD continues to provide traceable calibrations and measurements essential for industry and medical applications, including through specialized methods that require advances in and development of new measurement science. Division staff publish in premier journals (e.g., *Nature*, *Nature Physics*, and *Physical Review Letters*), give invited talks, create standard reference materials and databases, and provide calibration services that are unique to NIST and mandated by federal regulation.

The RPD subpanel's conclusions and recommendations are presented in Chapter 3. The subpanel recommends that the leadership of PML in collaboration with RPD and NIST leadership and the Office of Facilities and Property Management, conduct a safety review of all RPD laboratories and establish a plan to address deficiencies; PML and RPD leadership identify mission-critical single-point failures and implement remedies including addressing staffing and

PREPUBLICATION COPY—Uncorrected Proofs

training; leadership of PML consider a funding mechanism to support smaller innovative projects; and leadership of PML address inefficiencies in internal purchasing processes.

Nanoscale Device Characterization Division

The Nanoscale Device Characterization Division (NDCD) has assembled a strong team with world-class research and technical expertise to address PML priorities. The leadership structure is clearly defined and well organized. Five leadership teams oversee 13 major programs that address critical gaps in measurement science to support the domestic semiconductor industry; develop metrology for low-dimensional solid-state systems to advance quantum computing and sensing technologies; and establish fabrication methods, test structures, and instrumentation for characterizing nanoscale materials and devices.

These programs span atom-scale devices, nanoscale spectroscopy, advanced electronics, nanoscale processes and measurements, and alternative computing. The NDCD laboratories are well equipped and operated by highly competent technical staff, enabling effective execution of research aligned with PML priorities. The quality of the NDCD's research and technical programs is excellent. The division's activities are particularly thoughtful with respect to balancing its core mission (measurement, standards, technique, and instrumentation development) with emerging programs that address new national priorities, such as quantum information science, microelectronics, and artificial intelligence. The division engages with other top research groups to explore new models for scientific collaboration and project scope that leverage the unique strengths of PML. The NDCD management has implemented effective programs and processes to sustain and attract outstanding talent, ranging from senior scientists and midcareer professionals to postdoctoral researchers and PhD students. This commitment is evident in its budget planning and funding distribution strategies.

The division measures success through high-impact publications, patents, invited talks, and, when appropriate, Cooperative Research and Development Agreements with industry partners engaged in semiconductor materials, devices, characterization, and applications. Lack of permission to travel to disseminate and communicate results to other researchers is making it challenging for staff to maintain leadership in their fields. Overall, the review panel finds the NDCD's performance to be excellent.

The NDCD subpanel’s conclusions and recommendations are presented in Chapter 4. The subpanel recommends that PML leadership ensure that NCND scientists can travel to disseminate and communicate their results; and that the leadership of PML, in collaboration with the NDCD and NIST leadership and the Office of Facilities and Property Management prioritize maintenance and operations actions to ensure facilities and infrastructure do not endanger the core scientific mission.

Quantum Measurement Division

The Quantum Measurement Division (QMD) provides foundational metrological infrastructure for the United States, with a particular emphasis on SI realization, SI dissemination, quantum science, and development of new measurement science especially using quantum-based technologies. The division is organized into groups on Quantum Optics, Laser Cooling and Trapping, Fundamental Electrical Measurements, Applied Electrical Metrology, Mass and Force, and Atomic Spectroscopy (not covered herein as at the time of assessment, it was slated for closure, and was closed as of December 2025). Highly impactful technologies developed and advanced in the division include autonomous cooling of qubits, engineered Rydberg interactions of cold atoms, single-photon sources for quantum networks, the Kibble balance for the primary realization of mass, deployable quantum electrical standards, and mass and force calibration capabilities that range more than 11 orders of magnitude. Many patents have been filed, and the impacts of the division’s technology and metrology breakthroughs include several companies launched and improved SI dissemination such as tabletop standards for mass and torque transitioned to industry.

Individuals and teams in the QMD are world leading in development of new science as well as new measurement capabilities. A collaboration with the University of Maryland’s Joint Quantum Institute is central to this division’s dynamic research environment and culture. Division staff have received many prestigious awards, published in highly cited journals, and contributed to national policy leadership roles in other parts of the federal government. Departures and retirements of key members of the division’s leadership team, along with multiple current leaders nearing retirement age, indicate the importance of recruiting senior talent and succession planning. Facilities for the division frequently do not deliver the necessary environmental controls, leading to wasted staff time and inability to complete calibrations and

experiments, causing significant losses in productivity. The division is highly productive in dissemination, publishing frequently, participating in and leading documentary standards committees, and inventing revolutionary approaches to disseminating SI, including approaches that allow off-site and in situ calibrations.

The QMD subpanel's conclusions and recommendations are presented in Chapter 5. The subpanel recommends that PML leadership, in collaboration with the QMD and NIST leadership and the Office of Facilities and Property Management, address facilities upgrade needs from deferred maintenance, and that the QMD considers expanding use of dedicated technical staff for calibrations; that the QMD creates a communications plan with clear industry-relevant metrics and ensure the retention and availability of valuable databases such as those maintained by the Atomic Spectroscopy Group; and that the QMD collaborates with other PML divisions to formulate a unified strategic approach to quantum technologies.

Sensor Science Division

The Sensor Science Division (SSD) is responsible for dimensional, thermodynamic, optical radiation, and fluid flow measurements traceable through NIST to SI units via calibrations, standards, and new measurement solutions. The SSD is comprised of seven groups: Temperature and Humidity, Fluid Metrology, Optical Radiation, Remote Sensing, Fundamental Thermodynamics, Dimensional Metrology, and Surface and Interface Metrology. It realizes and disseminates three of the seven base units of SI—the meter, kelvin, and candela—for the United States and performs 43.7 percent of NIST's total calibrations (by revenue received) in service to industry, accredited laboratories, academia, and various federal government agencies. The SSD continues to perform at a level consistent with world-class metrology institutes. The organization's calibration and research capabilities are top tier, matching or surpassing those of other leading National Metrology Institutes. The technical programs effectively serve a wide range of stakeholders, including government, defense, and industry. However, funding is insufficient, especially to address the backlog of maintenance and upgrades required of aging infrastructure, such as uneven flooring creating a tripping hazard, and outdated equipment, such as aged heat sources requiring significant staff labor to keep running.

The SSD staff are leaders in their fields, routinely engaging with professional standards-writing bodies, publishing extensively in journals, and submitting invention disclosures and

patents. A large proportion of the staff are eligible for retirement, creating a risk of maintaining scientific expertise within the SSD. The division supports an effective mentoring program for emerging professionals that enables continuity in early-career development and knowledge transfer. Although the SSD is effective at disseminating its research outputs to current audiences, especially in government and the semiconductor and defense industries, it could provide greater value by additional outreach and collaborations with sectors such as advanced manufacturing and agricultural sensing.

The SSD subpanel's conclusions and recommendations are presented in Chapter 6. The SSD subpanel recommends that the Physical Measurement Laboratory, in collaboration with SSD and NIST leadership and the Office of Facilities and Property Management, prioritize infrastructure maintenance and upgrades that improve service delivery, improve research output, and enhance opportunities for new partnerships; diversify research and funding into new sectors to expand impact and relevance; continue to support emerging professionals and ensure appropriate staffing levels; and strengthen outreach and stakeholder engagement.

OVERARCHING THEMES, CONCLUSIONS, AND RECOMMENDATIONS

This report addresses the critical core mission of NIST in improving the precision and furthering the dissemination of SI units, in carrying out crucial calibrations of measurement instruments and devices used across the nation in industrial and government sectors, and in advancing measurement science generally. The panel observed outstanding work being accomplished by dedicated staff across all NIST PML divisions being reviewed.

The successful fulfillment of this mission is threatened by three critical issues: (1) lack of adequate staffing, especially at the senior level in many areas across all PML divisions; (2) severe laboratory infrastructure failures, affecting health and safety of personnel, ability to perform timely calibration for external customers, and threatening damage to valuable equipment; and (3) old, outdated instrumentation affecting the precision and reliability of measurements and calibrations. All three issues are caused or exacerbated by lack of sufficient funding.

These observations prompt three overarching conclusions and key recommendations:

PREPUBLICATION COPY—Uncorrected Proofs

Overarching Conclusion 7-1: The National Institute of Standards and Technology Physical Measurement Laboratory performs outstanding work accomplished by dedicated staff across all divisions being reviewed.

Overarching Conclusion 7-2: Staffing shortages have arisen at the National Institute of Standards and Technology (NIST) Physical Measurement Laboratory (PML) from long-standing issues (retirements of senior staff, better compensation elsewhere) and newer problems (government-wide incentivized departures). Staffing shortages are especially critical at an institution like PML, where staffing is already tight and certain critical services are only performed by single individuals. This leads to single-point failures to provide in a timely fashion aspects of the NIST core mission in calibration, dissemination of the International System of Units, measurement science, innovation, and industrial competitiveness.

Overarching Conclusion 7-3: Some laboratory conditions at the National Institute of Standards and Technology (NIST) Physical Measurement Laboratory are unsafe due to damage from flooding and leaks, and insufficient electrical supply. Poor environmental controls also lead to failures to provide aspects of the NIST core missions in calibration, standards, measurement science, innovation, and industrial competitiveness.

Overarching Conclusion 7-4: Outdated instrumentation is a potential single point of failure, and was identified as a major issue in two National Institute of Standards and Technology Physical Measurement Laboratory divisions (Radiation Physics and Sensor Science). Antiquated devices have decreased measurement accuracy and precision, and when they fail, work is delayed during repair or replacement.

Key Recommendation 7-1: The leadership of the National Institute of Standards and Technology Physical Measurement Laboratory should address critical staffing at all levels and ensure that training of more junior staff is adequate to avoid single-point failures.

Key Recommendation 7-2: National Institute of Standards and Technology (NIST) Physical Measurement Laboratory leadership, in coordination with NIST leadership and the Office of Facilities and Property Management, should begin a schedule of repair or replacement of laboratories that are subpar to eliminate hazardous safety conditions and serious hindrances to scientific work.

Key Recommendation 7-3: The leadership of the National Institute of Standards and Technology Physical Measurement Laboratory (PML) should assess equipment across the divisions, with a focus on equipment that can create single points of failure, or which limit the accuracy or precision of calibration services. PML should then reprioritize funding to replace or upgrade problematic equipment identified in its review.

1

Introduction

The National Institute of Standards and Technology (NIST) Physical Measurement Laboratory (PML) sets U.S. standards essential for industry, research, government, and ultimately for consumers and the public. This includes standards for mass, length, time, frequency, temperature, electricity, and electromagnetic radiation. The fundamental need for accurate measurements is reflected in the U.S. Constitution, which defines the government’s role to “fix the Standard of Weights and Measures” to promote consistency and uniformity in commerce and other activities.¹ PML’s priorities are determining the International System of Units (SI), disseminating the SI, quantum research and applications, fabrication for metrology and metrology for fabrication, and applications of physical measurement. Within these priorities are other aspects of the NIST mission such as providing calibration services to industrial and other partners to enable conformity, accreditation, and traceability of products, services, and research outcomes. Determining the SI has recently taken major advances to develop new procedures and tools to define standard measurement units based on laws of physics and fundamental physical constants as opposed to a physical artifact such as the metal cylinder that formerly served as the International Prototype Kilogram.

This work requires developing procedures and tools to revolutionize how measurements are made in every application, maintaining instruments that can calibrate force compression or tension as large as 4.448 MN (1 million pounds-force) (Bartel et al. 1997), as well as developing devices and metrics for nanoscale environments and exploring and leveraging quantum mechanical properties. Within the divisions reviewed in this assessment, PML includes expertise in several areas: microsystems, nanotechnology, and nanoscale device characterization, to advance nanofabrication and nanomanufacturing; radiation physics, to provide accurate characterization of ionizing radiation and radioactivity; quantum processes and controls, to

¹ 1. U.S. Const. art. I, § 8, cl. 5.

advance a wide spectrum of new understanding at quantum scales; and measurement science, including dimensional, thermodynamic, optical radiation, and fluid flow metrology. Work at PML supports NIST’s overall strategic goals of accelerating innovation in critical and emerging technologies such as quantum science, artificial intelligence, biotechnology, and semiconductors; bolstering U.S. leadership in standards development; accelerating commercial adoption of U.S. innovations; and building research infrastructure that enables innovation in critical and emerging technologies (NIST n.d.)

PML’s total budget in fiscal year 2025 was \$241.7 million. The scientific and technical research services base budget represents the bulk of funding and has been falling since 2021, from above \$150 million in 2021 to now \$140 million in 2025. Scientific and technical research services non-base funding totaled \$47.8 million, federal and non-federal government and cooperative research and development agreement funding totaled \$25.8 million, calibrations totaled \$3.3 million, and other funding including from the CHIPS and Science Act totaled \$16 million in 2025 (Kushmerick 2025). Other agency funds for PML work come primarily from defense agencies such as DARPA, the Department of War, and the services. Non-defense agencies include NASA, the Department of Energy, and the Department of Homeland Security. There is a separate appropriation to NIST for Construction of Research Facilities, which includes Safety, Capacity, Maintenance, and Major Repairs. That funding has been approximately flat averaging about \$97 million between FY2020–FY2025, with \$88 million appropriated in 2025 (AIP 2026). When including all PML-specific funding streams, total funding has been approximately flat since FY2020. Given inflation, flat overall budgets for PML and for NIST-wide construction and maintenance of facilities means that funding has fallen relative to costs. The PML and facilities funding levels are outside of PML leadership’s control, but the panel was tasked with assessing the budget, facilities, equipment, and human resources, and noted where the budget is causing constraints in PML’s ability to deliver on its mission.

STATEMENT OF TASK

In 2025, at the request of the Director of NIST, the National Academies convened the Panel on Assessment of the NIST Physical Measurement Laboratory, hereafter referred to as “the panel.” The panel was established to review five divisions in PML for fiscal year 2025: (1)

Microsystems and Nanotechnology, (2) Radiation Physics, (3) Nanoscale Device Characterization, (4) Quantum Measurement, and (5) Sensor Science. The assessment process was designed to consist of an in-person site visit and drafting of a comprehensive report. The panel carried out the responsibilities outlined in the statement of task, which is reprinted below:

The National Academies shall appoint a panel to assess independently the scientific and technical work performed by the National Institute of Standards and Technology (NIST) Physical Measurement Laboratory (PML). The panel will review technical reports and technical program descriptions prepared by NIST staff and will visit the facilities of the Physical Measurement Laboratory. Visits will include technical presentations by NIST staff, demonstrations of NIST projects, tours of NIST facilities, and discussions with NIST staff. The panel will deliberate findings in closed sessions and will prepare a report summarizing its assessment findings and recommendations.

NIST has requested that the laboratories be assessed against the following broad criteria:

1. Assess the organization's technical programs.
 - How does the quality of the research compare to similar world-class research in the technical program areas?
 - Is the quality of the technical programs adequate for the organization to reach its stated technical objectives? How could it be improved?
2. Assess the portfolio of scientific expertise within the organization.
 - Does the organization have world-class scientific expertise in the areas of the organization's mission and program objectives? If not, in what areas should it be improved?
 - How well does the organization's scientific expertise support the organization's technical programs and the organization's ability to achieve its stated objectives?
3. Assess the adequacy of the organization's budget, facilities, equipment, and human resources.
 - How well do the facilities, equipment, and human resources support the organization's technical programs and its ability to achieve its stated objectives? How could they be improved?
4. Assess the effectiveness by which the organization disseminates its program outputs.
 - How well are the organization's research programs driven by stakeholder needs?

PREPUBLICATION COPY—Uncorrected Proofs

- How effective are the dissemination methods and technology transfer mechanisms used by the organization? Are these mechanisms sufficiently comprehensive?
- How well is the organization monitoring stakeholder use and impact of program outputs? How could this be improved?

CONDUCT OF THE ASSESSMENT

The panel comprising 24 volunteers with subject-matter expertise aligned with the scientific and technical work conducted at PML convened in Gaithersburg, Maryland, on September 9–11, 2025, to conduct an in-person assessment of PML. During the review, the panel engaged with PML leadership and staff, who delivered comprehensive presentations detailing the center’s research activities, operations, and strategic priorities. These sessions were complemented by guided tours of PML facilities and substantive, interactive discussions between panel members and PML personnel.

In formulating its evaluation, the panel drew upon the collective technical acumen, disciplinary breadth, and professional experience of its members. The assessment employed a qualitative methodology, grounded in the materials submitted by PML, as well as the content of presentations, poster sessions, facility tours, and associated discussions. The content of this report can be assumed to be based on those qualitative assessments, and citations to appropriate sources are provided in cases where further information and evidence were available. Although the report does not address every individual research project or program, the omission of specific topics should not be interpreted as an indication of negative judgment. Rather, the panel focused its commentary on areas it considered most salient based on the information made available. In its assessment, the panel made qualitative statements about PML’s achievements (e.g., high-quality publications, world-class research); its definitions of these descriptors are provided in Appendix B. The resulting report emphasizes PML’s ongoing scientific and technical work, identifying key opportunities and challenges as observed during the site visit.

It is important to underscore that NIST maintains a distinct advisory entity, the Visiting Committee on Advanced Technology, which is charged with addressing broader questions related to strategic direction and research alignment across the agency’s laboratories. Accordingly, this review does not include an evaluation of whether PML is pursuing the

“appropriate” lines of research, as such determinations fall beyond the purview of the panel’s mandate.

STRUCTURE OF THE REPORT

Following this introductory chapter, the report is organized into six subsequent chapters, where Chapters 2–6 align with the five divisions the panel reviewed, and Chapter 7 summarizes the panel’s assessment. Specifically, Chapter 2 presents the panel’s review of the Microsystems and Nanotechnology Division vision; Chapter 3 presents the review of the Radiation Physics Division; Chapter 4 presents the review of the Nanoscale Device Characterization Division; Chapter 5 presents the review of the Quantum Measurement Division; and Chapter 6 presents the review of the Sensor Science Division. Chapter 7 summarizes the panel’s conclusions and presents both overarching and chapter-specific recommendations.

REFERENCES

- Bartel, T., S. Yaniv, and R. Seifarth. 1997. “Force Measurement Services at NIST: Equipment, Procedures, and Uncertainty.” National Institute of Standards and Technology. <https://www.nist.gov/system/files/documents/calibrations/97ncs4b.pdf>.
- Kushmerick, J. 2025. “Physical Measurement Laboratory Overview: NASEM Review of Gaithersburg Divisions.” Presentation to the committee. September 9. Gaithersburg, MD. Including updated actual obligated budget figures from Patrick Hovis, National Institute of Standards and Technology, March 31, 2026.
- NIST (National Institute of Standards and Technology). n.d. “NIST Strategy for American Technology Leadership in the 21st Century.” NIST Office of the Director. <https://www.nist.gov/director/strategic-priorities>. Accessed February 18, 2026.
- AIP (American Institute of Physics) 2026. FYI Budget Tracker: FY2026 National Institute of Standards and Technology. Accessed March 10, 2026. <https://www.aip.org/fyi/fy2026-national-institute-of-standards-and-technology>.

2

Microsystems and Nanotechnology

BACKGROUND ON THE MICROSYSTEMS AND NANOTECHNOLOGY DIVISION

The Microsystems and Nanotechnology Division (MND) focuses on advancing fabrication and metrology at the nanoscale for improved device and measurement systems. The division aims to enable critical and emerging technologies by making traceable nanometer scales, understanding photon interactions and optomechanics, and developing integrated microsystems and nanofabricated devices for biomedical measurement. Its work supports a wide variety of industries and applications, from photonics and semiconductor manufacturing to biophysical and biomedicine measurements. All of MND’s research groups are supported by a team of design and fabrication engineers who maintain a state-of-the-art nanofabrication facility. At the time of this assessment, the MND employed a total of 83 staff, of which 25 were federal employees and 58 were associates.¹ In fiscal year 2025, MND had a budget of \$24.03 million, of which \$22.92 million were scientific and technical research services funds, \$913,000 were other agency funds, and \$197,000 were other working capital funds² (PML 2025).

TECHNICAL PROGRAMS

The MND is organized into three programmatic thrusts: Nanostructure Fabrication and Measurement (NFM); Photonics and Optomechanics (POM); and Biophysical and Biomedical Measurement (BBM). The research programs within each thrust are well aligned and focused on chip metrology, quantum photonics, and establishing standards for biological systems. Not only

¹ Associates are domestic and foreign guest researchers from academia, industry, and other government agencies who collaborate on NIST research projects and use NIST facilities but are not NIST employees.

² Other agency funds are funding of NIST projects from other government agencies. Working capital funds include external reimbursable activity such as calibrations and internal reimbursable activity such as calibration operations and service development and standard reference material production and service development.

do these programs address the main challenges of stakeholders, but they also address the field in general. Overall, the MND's thrusts are well aligned with National Institute of Standards and Technology (NIST) strategic goals (see Chapter 1).

The NFM Group focuses on fabricating and measuring nanostructures to support a broad range of topics centered on semiconductor metrology, quantum photonics, and nanoparticle standards. The program provides design and process integration expertise to establish advanced chip-scale optical microfabrication platforms. To do so, the group fabricates many state-of-the-art integrated micro- and nano-optical chips to address challenges in metrology and application needs with scalability and traceability. Key efforts include improving nanoscale International System of Units (SI) traceability, developing scanning electron microscopy (SEM) calibration standards, and advancing hybrid metrology techniques. The NFM Group also focuses on integrating quantum emitters with photonic structures and characterizing nanoparticles using traceable SEM and atomic force microscopy methods. Particularly notable is the Cooperative Research and Development Agreement (CRADA) with a leading semiconductor metrology tool vendor, under which a standard (termed Accurray, short for Accurate Array) was developed to characterize optical and electron-beam microscopy tools. Additional notable accomplishments include innovative electron-beam modeling capabilities that have enabled the development of metrology tools to measure buried surfaces within state-of-the-art transistor architectures, and the fabrication of a single quantum dot device, which provides valuable insights toward future nonclassical light sources. Despite these accomplishments, the impact of NFM could be maximized by earlier, strategic engagement with a broader range of stakeholders across semiconductor manufacturing and related efforts in other divisions. For example, enhancing the electron-optics in SEM is more reactionary to the immediate needs of stakeholders rather than forward-looking to develop advanced metrology for nano-scale fabrication needs in advanced complementary metal-oxide-semiconductor fabrication.

The POM Group designs, fabricates, and tests chip-scale photonic and optomechanical devices for quantum computing, artificial intelligence (AI), and precision sensing. POM's research programs focus on on-chip light sources, optomechanical sensing, agile light manipulation, and device metrology to address chip-scale manufacturing of optic devices; physical measurement, stability, and traceability of chip-scale light sources; and quantum photonic devices from stakeholders. The POM team also develops metrology tools for

PREPUBLICATION COPY—Uncorrected Proofs

characterizing materials and devices that are used in advanced communications and sensing. The team successfully developed an innovative chip-based integrated nanophotonic platform for stakeholders. This platform has led to a chip-scale optical clock with an integrated atomic reference that operates over an ultrawide frequency range (terahertz to gigahertz) and to a cavity optomechanic sensor with a low noise equivalent acceleration of $32\text{ng}/\sqrt{\text{Hz}}$ at 6.8 kHz. The platform has also resulted in validation and traceability by other PML divisions at Gaithersburg and Boulder. The POM Group demonstrates impressive, relevant, and new capabilities in each of the above-mentioned areas and is underpinned by many notable publications in high-impact general science journals such as *Nature*. Each POM project is well supported by external stakeholders from industry and government agencies. Most impressive is the cohesive collaboration among team members involved with on-chip light generation with modulators toward optical clocks, mass sensing, and device metrology.

The BBM Group pioneers chip-scale metrology for life sciences and biomanufacturing and makes extensive use of the outstanding nanofabrication facilities at NIST. Programs include high-throughput biometrology tools (e.g., biosimeters and cytometers), semiconductor-based biosensing platforms, and microphysiological systems for drug testing. The BBM Group also leads efforts in biomolecular standards, such as structural characterization of monoclonal antibodies, supporting innovation in biologics and AI-driven drug discovery. The group has a very clear identification of stakeholders and targets defining new standards in the field. Examples of these stakeholders include the National Institutes of Health (Complement Animal Research in Experimentation program, clinical trials on chips, Validation and Qualification Network), the National Science Foundation iCORP program, and the NIST Microphysiological Systems Stakeholder group, which includes the Food and Drug Administration, and the National Security Commission on Emerging Biotechnology. Standouts in this thrust include the bioradiation standards involving careful quantification of deoxyribonucleic acid (DNA) damage and the remarkable accuracy of flow cytometry. Specifically, the BBM Group implements state-of-the-art chip-scale microfluidic systems to measure flow rate traceable to 100 pico-liter/minute, enabling precise and traceable metrology for flow cytometry and micro biomembrane applications. With a custom-fabricated 34-GHz electron parametric resonance spectrometer, the group has measured and delivered the first validated structural ensemble of a monoclonal antibody, which can subsequently be used for new drug discovery. The BBM Group also

PREPUBLICATION COPY—Uncorrected Proofs

initiated a new SI effort for measuring radiation dose to biological materials that correlates the physical dose measurement in gray with measurement of damage to DNA. This innovative measurement technique has been supported by experiments involving gamma-radiation exposure to DNA, and the group aims to produce a prototype device for dosimetry of low-level radiation measurement in cancer treatment.

SCIENTIFIC EXPERTISE

The MND has top experts across research fields in nanofabrication, microscopy, photonics, mechanics, and biotechnology, and includes seven fellows of scientific societies. Division staff produce high-quality research publications, hold leadership positions within professional societies, and maintain strong relationships with a wide variety of major stakeholders. For example, the BBM Group leads several workshops and initiatives with key industry working groups, such as the NIST Microphysiological Systems Stakeholder group, the National Institutes of Health Validation and Qualification Network, and the National Security Commission on Emerging Biotechnologies, among others. As another example, the MND has been a key part of the Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act program through the support of nanofabrication services and 12 distinct CHIPS projects across the division. The expertise within the MND is particularly important for delivering the Physical Measurement Laboratory's (PML's) strategic priorities,³ as it also supports several crosscutting programs. A prime example is the nanofabrication integration team, which enables the division and PML to provide world-class nanofabrication services that have created fruitful, long-term relationships with industrial and academic partners (e.g., multiple co-authored patents with a quantum computing company). Testimonials from select partners highly praised the expertise of the group. However, recent personnel departures have caused challenges for the division and have already led to lost expertise and delayed outcomes for stakeholders. While the division is currently managing these challenges, continued disruption could present a critical threat to maintaining the outstanding expertise of the group.

³ PML's research priorities are as follows: realizing the international system of units (SI); disseminating the SI; quantum research and applications; fabrication for metrology/metrology for fabrication; and applications of physical measurements.

The NFM Group includes leading experts in electron and optical microscopy with unique skills acquired through partnerships with external industry partners as well as roles within the CHIPS program. This expertise has already been applied to improving NIST’s capabilities to fabricate precision nanostructures and devices. However, it is not clear whether the group will continue to have sufficient expertise to fully address the long-term needs of stakeholders given retirements and departures. Expansion of the knowledge base in semiconductor metrology—through increases in staffing, leadership within the field, or collaboration with other divisions of NIST—could further increase the impact of this group’s work.

The POM Group includes experts in on-chip nonlinear processes, lasing, photonic integration, metamaterials, and optomechanics. Expertise in this division is key for realizing initiatives such as NIST-on-a-chip, which relates to the NIST priorities of disseminating the SI and quantum research and applications. As such, several of the initiatives support other NIST divisions in their missions. Expertise in this group is world leading, as they are delivering publications in high-impact journals such as *Nature* and demonstrating first-of-a-kind capabilities, including bridging the green laser emission gap to provide 450 to 600 nm tuning range and performing extremely precise optomechanical measurements of 67 GHz acoustic wave with femtometer precision.

The BBM Group includes expertise in microfluidics, flow cytometry, radiation effects in biological systems, and complementary metal-oxide-semiconductor sensors. The group is working to expand the SI and improve the accuracy of measurement, leveraging the division’s strengths in fabrication. The group’s significant technical expertise is reflected in its publications, leadership in defining new standards, and 11 awarded patents. Without world-class expertise, this group would not have been able to produce the first serial flow cytometry measurements or to develop methodology for standardizing radiation dosing. The group’s expertise will continue to advance the mission of PML, and it is critical for staffing to be maintained (and, when possible, expanded) at its current, highly productive level.

FACILITIES, EQUIPMENT, AND HUMAN RESOURCES

The facilities within the MND have led the division to achieve many “first-in-the-world” or “world-class” results despite serious infrastructure challenges, such as floods and leaking

ceilings (e.g., the optical metasurface lab in POM had a water leak directly over one of their state-of-the-art lasers), that have caused significant delays in research and frustration among staff. The nanofabrication facility serves all NIST, not just the MND, and many commercial stakeholders, and has more than 100 semiconductor processing tools. It is one of the premier nanofabrication facilities in the world, accessible to a wide range of groups and commercial stakeholders. The facility is supported by dedicated staff who have many years of experience with advanced semiconductor fabrication tools. Through the CHIPS and Science Act, the nanofabrication facility has now acquired several new, state-of-the-art tools. The current staff, however, are overloaded with bringing these tools online while also maintaining and supporting existing tools. Several impending staff retirements and departures of junior staff compound this overload, representing a serious concern for the MND and its stakeholders.

The MND employs many postdoctoral fellows and early-career staff who are excited to be at NIST and are very satisfied with their individual research. However, they have voiced the desire for a stronger social community at NIST (e.g., through the re-opening of the cafeteria), which would provide more opportunities for them to meet people outside of their immediate team. Postdoctoral fellows have also expressed a desire for clear guidance regarding the steps needed to become a federal employee.

Leaders of the MND groups have had different experiences in hiring postdoctoral fellows through the NIST Professional Research Experience Program.⁴ Unlike the BBM lead, the NFM and POM leads report that they have had difficulty in recruiting postdoctoral researchers because of long lead times and salary issues. All three leads report that getting cost-of-living adjustments for their postdoctoral researchers is difficult (which the researchers, themselves, have echoed).

EFFECTIVENESS OF DISSEMINATION OF PROGRAM OUTPUTS

The MND has successfully disseminated its research output and technology advances through the publication of nearly 100 science articles in high-impact general science and field-specific journals, such as *Nature Communications*, *Optics Letters*, and *Nature Photonics*, over

⁴ NIST's Professional Research Experience Program is a collaborative effort with several universities to provide research funding and training at NIST for students, postdoctoral scholars, senior researchers, and faculty. The program aims to develop scientists and engineers in measurement science and standards research and, more broadly, to grow the U.S. workforce in science, technology, engineering, and mathematics (NIST n.d.).

the past 4 years. Precision integrated nano-scale electronic and optical-mechanical devices, which enable precision metrology in chip manufacturing, quantum photonics, and nano-particle standards, have been transferred to stakeholders, such as the Air Force Research Laboratory, and to industry partners, including metrology, technology, and pharmaceutical companies. The MND established 17 CRADAs, 5 transfer agreements, and 34 patent disclosures in the past 4 years. While it was clear from select testimonials that the division has been effective in its engagement with stakeholders, the MND does not have a systematic approach to tracking informal engagements with the program. (NIST's Technology Partnerships Office does track formal engagements such as patent licensing and CRADAs.) Because many key technologies related to the division, such as semiconductors, quantum science, and microphysiology, are evolving rapidly, the panel encourages the staff and associates to attend major conferences and participate in stakeholder working groups (e.g., advisory boards, regular industry road-mapping exercises, professional societies) to engage external communities frequently, early, and strategically. Doing so will help to expand and guide future research programs and disseminate the division's state-of-the-art technologies to broader communities.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion 2-1: The research within the Microsystems and Nanotechnology Division is world leading, and the division continues to define new, emerging technologies. Examples include defining a new unit for radiation exposure and achieving new standards and record precision in acceleration measurement. However, the research approach sometimes appears reactionary to immediate stakeholder needs rather than forward looking and strategic, and could benefit from earlier engagement with stakeholders to help the division maintain its premier strength and leadership.

Recommendation 2-1: The leadership of the National Institute of Standards and Technology Physical Measurement Laboratory (PML) should encourage group leaders to participate in leadership opportunities within their respective research communities. Staff and associates should be encouraged to attend major conferences and stakeholder working groups to connect with external communities frequently. Microsystems and Nanotechnology Division leadership should engage earlier with

PREPUBLICATION COPY—Uncorrected Proofs

semiconductor industry and metrology tool vendors to help define new research directions and metrology and measurement innovation goals, and to improve long-term strategy roadmaps at the group level.

Conclusion 2-2: The nanofabrication facility is world class and has acquired new, state-of-the-art instrumentation because of the Creating Helpful Incentives to Produce Semiconductors and Science Act. The Microsystems and Nanotechnology Division's integration team is critical for facilitating fabrication efforts throughout the National Institute of Standards and Technology and for other stakeholders. However, the current staff are overstretched in managing the expanding facility, and research capabilities have suffered, and will continue to suffer, because of staff attrition and anticipated retirements.

Recommendation 2-2: The leadership of the Physical Measurement Laboratory should prioritize support for the nanofabrication facility, including providing specific, dedicated funds to hire junior staff, whom senior staff can mentor and train to set up new tools, support existing tools, and respond to the needs of expanded programs.

Conclusion 2-3: The Microsystems and Nanotechnology Division employs many postdoctoral fellows and early-career staff who are very satisfied with their individual research. However, postdoctoral fellows have expressed a desire for clearer guidance regarding steps that are needed to advance their career.

Recommendation 2-3: The leadership of the National Institute of Standards and Technology (NIST) and the Physical Measurement Laboratory (PML) should evaluate their hiring practices, mentoring and professional development programs, and community-building efforts for postdoctoral researchers to improve their experience at NIST. Specifically, NIST leadership should work with universities in the Professional Research Experience Program to minimize hiring delays and, to the extent possible, secure annual cost-of-living adjustments for postdoctoral researchers. PML leadership should establish a mentoring program to advise postdoctoral researchers on their NIST career, with clear guidance on the pathway

PREPUBLICATION COPY—Uncorrected Proofs

from early-career associate to federal employee. To help foster a sense of community, NIST leadership should take concrete steps to enable researchers to connect with each other, such as reopening shared spaces like the cafeteria.

Conclusion 2-4: The stakeholder testimonials suggest that the Microsystems and Nanotechnology Division has positive, beneficial interactions with industry, but they are specific, limited examples. It would be useful to add additional laboratory-wide metrics to evaluate the long-term impact of programs.

Recommendation 2-4: The leadership of the National Institute of Standards and Technology (NIST) Physical Measurement Laboratory (PML) should consider tracking additional metrics to review dissemination and demonstrate impact. For example, PML could evaluate the career path of associates trained through NIST programs, or track product lines developed, instruments impacted, financial impacts on industry sector sizes, or staff members trained. These metrics could be collected through stakeholder surveys and could help demonstrate the long-term value and impact of PML.

REFERENCES

- NIST (National Institute of Standards and Technology). n.d. “NIST Professional Research Experience Program (PREP).” NIST Academic Affairs Office. <https://www.nist.gov/iaao/academic-affairs-office/prep>. Accessed February 17, 2026.
- PML (Physical Measurement Laboratory). 2025. Read-Ahead Material for NASEM Assessment of PML. National Institute of Standards and Technology, Gaithersburg, MD.

3

Radiation Physics

BACKGROUND ON THE RADIATION PHYSICS DIVISION

The Radiation Physics Division (RPD) is responsible for developing, maintaining, and disseminating standards to accurately and precisely measure ionizing radiation. This is a critical task in radiation protection, as evidenced by federal regulation (Title 10 of the Code of Federal Regulations [10 CFR] 20.1501; NRC 1991), which requires use of radiation detectors with calibrations traceable to NIST for all radiation safety surveys. It is also critical for treating and diagnosing disease, as evidenced in 10 CFR 35.630 (NRC 2003), which requires use of radiation detectors with calibrations traceable to NIST to characterize radiotherapy beams and nuclear medicine drugs. The RPD also supports nation-critical programs, such as nuclear energy, homeland security, and environmental monitoring, by producing Standard Reference Materials, performing calibrations, developing radiation detection and metrology techniques, and maintaining radiation interaction and dosimetry reference databases. At the time of this assessment, the RPD employed a total of 45 staff, of which 41 were federal employees and 4 were associates.¹ In fiscal year 2025, RPD had a budget of \$14.97 million, of which \$10.87 million were scientific and technical research services funds, \$1.87 million were other agency funds, and \$2.23 million were other working capital funds² (PML 2025).

¹ Associates are domestic and foreign guest researchers from academia, industry, and other government agencies who collaborate on NIST research projects and use NIST facilities but are not NIST employees.

² Other agency funds are funding of NIST projects from other government agencies. Working capital funds include external reimbursable activity such as calibrations and internal reimbursable activity such as calibration operations and service development and standard reference material production and service development.

TECHNICAL PROGRAMS

The RPD is divided into three groups: the Dosimetry Group, the Neutron Physics Group, and the Radioactivity Group. The Dosimetry Group is tasked with advancing and standardizing the measurement of specific energy imparted by ionizing radiation to matter (i.e., absorbed dose). Their work is central to fields such as radiation protection, radiation oncology, material characterization, and material hardening. This group has also designed water calorimeters and ultrasonic thermometry, which enables the characterization of 100–300 kV x-rays, low- to mid-energy gamma rays, and pulsed MeV electron beams. These devices are used in fields such as diagnostic imaging, brachytherapy cancer treatment, and particle beam radiotherapy. The Dosimetry Group is establishing traceability standards for low-energy electron-beam industrial dosimetry, expanding the scope of x-ray calibration services to include dose standards for radiation biology, and developing deoxyribonucleic acid–based dosimetry to directly measure radiation dose in biological systems.

The Neutron Physics Group is responsible for developing and maintaining physics standards for nuclear fission and fusion power generation, maintaining national security, aiding industrial manufacturing, and radiation protection. Their recent accomplishments include developing a new imaging technique using the NIST cold neutron imaging facility to evaluate systems such as batteries and fuel cells with 1-micrometer spatial resolution, enable the characterization of novel materials, and develop quantum information science techniques with precisions far higher and measurement times far shorter than other methods. The Neutron Physics Group is also developing novel particle-detection technologies in support of studies of neutron beta decay, fast neutron metrology, and dosimetry for basic sciences, accelerator cancer therapy facilities, and space utilization. The group is tasked with obtaining the most precise measurement of the neutron lifetime, which is needed to enable quantum realization of many International System of Units (SI) measures, establishing neutron interferometry for novel materials and quantum information science, and developing multimodal neutron and x-ray tomography methods for materials characterization. This work will be central to advancing the federal government's goals of producing next-generation nuclear fission reactors and nuclear fusion reactors. Outside of the base funding that supports work in the division, additional support comes from NIST's Innovations in Measurement Science program, which funds a very small

PREPUBLICATION COPY—Uncorrected Proofs

number of large-scale projects. This limits opportunities to develop small and early-stage research projects, which can stifle innovation.

The Radioactivity Group's mission is to develop, maintain, and disseminate radioactivity standards; develop and apply radioactivity measurement techniques; and enable customers to demonstrate compliance with federal and state regulations for working with radioactive materials and radiation-emitting devices. Recent accomplishments include the "TrueBq" initiative, which enables the activity calibration of liquid sources at the level of a single Becquerel (Bq, decay per second). Most recently, this group has developed standards to enable the safe and effective use of alpha emitters, such as ^{224}Ra and ^{225}Ac , for radiation cancer therapy and has developed new detectors using transition edge sensor technology of minuscule amounts of radioactive material, which has far-reaching impacts from improving cancer treatments to ensuring the safety of nuclear waste cleanup.

In the past year, the RPD's work has enabled the safe and effective radiation treatment of approximately 1 million cancer patients; has enabled the safe regulation of radiation dose exposures to about 40 million mammogram patients; has helped protect about 4 million radiation workers; has been used to standardize the sterilization of medical products, food irradiation, and blood irradiation; and has reduced the threat of terrorist attacks using illicit radioactive materials. It has also enhanced the accurate measurements of patient doses for radiopharmaceuticals, and promoted public safety by better detecting and quantifying releases of radioactive contaminants into the environment.

The RPD is also a leader in international radiation metrology, among France's International Bureau of Weights and Measurements, Germany's Physikalisch-Technische Bundesanstalt, and the United Kingdom's National Physical Laboratory. NIST's RPD members hold important positions in international decision-making bodies, including the American Society for Testing and Measurement International, the Council on Ionizing Radiation Measurements and Standards, the American Association of Physicists in Medicine, and the Health Physics Society.

Yet the RPD calibration services, which provide federally required radiation detector calibrations for hospitals, industry, and nuclear power, were found to be insufficiently prioritized by NIST, due to insufficient funding. Each calibration facility is staffed by a single individual without having a backup staff member to provide calibration services if the main staff member is

absent and the equipment used in these calibration facilities are not up to date. Adequate funding for calibration infrastructure and additional staff is necessary to maintain required services to complete these federally required calibrations in a timely manner.

SCIENTIFIC EXPERTISE

The RPD possesses world-class expertise in radiation measurement science and is a leader in realizing and disseminating key SI units: the Bq, gray, and sievert. The three groups that make up this division (Radioactivity, Dosimetry, and Neutron Physics) collectively sustain an internationally recognized program in fundamental physics research, detector development, calibration services, and measurement standards. This expertise is reinforced through collaborations with government agencies and industry and international bodies, and is validated by the division's leadership roles in the International Bureau of Weights and Measures, International Electrotechnical Commission (IEC), Institute of Electrical and Electronics Engineers, ASTM International, and American Association of Physicists in Medicine.

At the time of the assessment, staffing for the RPD included 12 professionals in Dosimetry, 14 in Neutron Physics, and 18 in Radioactivity. There are approximately 10 unfilled positions. The publication output for the division has been active, with more than 99 publications over the past 4 years in 55 journals with 371 co-authored affiliations. The publication output is consistent with peer academic physics and metrology researchers.

The RPD demonstrates global leadership in radionuclide standardization (more than 100 radionuclides); dosimetry of photons, electrons, and charged particles; and neutron science, with world-best uncertainty (0.1 percent in cold neutron fluence). Cutting-edge efforts such as the TrueBq project, cryogenic quantum sensors, structured neutron interferometry, and advanced photonic calorimeters highlight the division's capacity for innovation at the intersection of metrology and fundamental physics. Awards to staff and recognition through fellowships, NIST and Physical Measurement Laboratory (PML) medals, and international honors confirm its scientific standing. Areas for future enhancement include expanding electron-beam dosimetry for advanced radiation processing and further standardization to support emerging radiotherapy technologies.

Notwithstanding the world-class researchers assembled in the RPD, several mission-critical projects may be significantly impacted by the departure of key personnel, particularly given insufficient staffing to provide timely replacements due to budget constraints. For example, the instrument calibration facility was managed by a single individual, and when this individual unexpectedly retired, calibrations could not be performed. Although a replacement was eventually assigned, the transition resulted in a 3-month delay. The lack of photon detectors calibrated by NIST during this 3-month period was especially important considering the federal radiation safety regulations that require all photon radiation detectors to have their traceability at NIST. Generally, only one person is trained to perform radiation device calibrations, and therefore no instrument calibrations can occur when that person is unavailable. In one case, the unplanned retirement of the person who performs x-ray detector calibrations caused instrument calibrations to cease for 3 months. Critical tasks and services that rely on a single individual risk mission success if unavailable. Identifying and addressing these vulnerabilities through cross-training, succession planning, and alternative methods would mitigate these potential failures.

FACILITIES, EQUIPMENT, AND HUMAN RESOURCES

While the RPD is accomplished and exhibits strong international leadership, its productivity and ability to support federally mandated calibration programs, required under federal law, are constrained by a lack of funding and limited personnel.

The RPD Neutron ^{252}Cf calibration facility, for example, has warped metal floors (through which the subfloor is visible), only one emergency egress, a degraded neutron shield, and only three electrical outlets in the entire facility. The photon-radiation detector calibration facility, alternatively, had its infrastructure recently updated, yet the calibration equipment central to their mandate is easily more than 30 years old. As an example, the facility still uses Keithley Model 617 electrometers, which were manufactured in 1984. The reliance on antiquated calibration equipment may eventually lead to interruptions in calibration services if one of these devices fail, due to the difficulty in getting replacement parts for these old devices. This deteriorating infrastructure also is a cause of sample contamination, lacks temperature and humidity control (a requirement for high-precision electronic measurements and Air Kerma standardization), and lacks stability in its electric power. Aging infrastructure, water damage,

flooding risks near radioactive sources, unstable flooring, and inadequate electrical setups pose safety hazards and hinder calibration and research activities. An occupational and radiation safety review would help address these concerns. Another concern is the burdensome requirements procedure related to purchasing, such as obtaining three quotes for low-cost items, which consumes excessive time. Establishing a cost threshold below which multiple quotes are not required would improve efficiency.

The Radiation Physics Division Calibration Laboratory commonly calibrates its radiation detectors using equipment more than 30 years old, which is another potential single point of failure. These antiquated devices not only have decreased measurement accuracy and precision relative to newer models, but when they fail, as all electronic equipment eventually will, a significant amount of time will be required to find an appropriate replacement and to incorporate this new device into the current system. As noted in Recommendation 3-2, the RPD should identify key projects that are vulnerable to single points of failure and implement succession planning and relevant training to mitigate future interruptions.

The number of mission-critical staff in the RPD is also lower than is reasonable to fulfill the RPD's mission, as articulated in the preceding section. The successful output of the RPD is owing to the dedication and hard work of the staff, who work long hours and constantly "do a lot with very little." This is unsustainable. A program model that can sustainably deliver required calibration services as well as make groundbreaking advances in radiation physics requires higher staffing, modern electronic equipment, and a safe and updated laboratory infrastructure.

EFFECTIVENESS OF DISSEMINATION OF PROGRAM OUTPUTS

The Dosimetry Group helps establish radiation standard units by employing x-ray beams, cesium and cobalt irradiators, and a linear accelerator in conjunction with a wide variety of ion chamber detectors. Dissemination of the standard occurs through their calibration and measurement services that support many stakeholders. The Dosimetry Group has several projects that provide traceability of radiation dose to end users, including x-ray and gamma-ray calibrations, brachytherapy seed calibrations, water calorimetry research, and remote sensing dosimetry research. Specifically, these calibrations and associated laboratory functions are

critical for providing services to secondary laboratories. Comparisons of NIST irradiators with irradiators at other facilities have resulted in several publications.

In addition to the standard calibration deliverables, members of the Dosimetry Group have also chaired and authored reports from the National Council on Radiation Protection and created NIST handbooks for public consumption, such as the National Voluntary Laboratory Accreditation Programs. They continue to develop and revise the standards of the American National Standards Institute, the Institute of Electrical and Electronics Engineers, International Organization for Standardization, and IEC, as well as participate in the development of Federal Emergency Management Agency documents, specifically in nuclear event response. From 2022 to 2025, the NIST RPD performed 160 calibration service activities, produced 15 scientific publications, and presented 9 invited talks.

The Neutron Physics Group has a diverse portfolio of calibration and irradiation activities to disseminate the standards. The calibration activities involve the calibration of neutron instruments and dosimeters by employing several specialized neutron sources. One specialized method, the manganese sulfate bath, offers a service to evaluate neutron emission rates. NIST's manganese sulfate bath facility is the most accurate method for measuring the rate of neutron emissions from a radioactive source in the United States. This technique is then coupled with other techniques to increase the overall precision in that source's neutron emission rate. Customers include national laboratories and commercial suppliers who sell calibrated neutron sources to their clients. Owing to the technically challenging nature of these measurements, the method strikes a balance between research and development and services partly by comparing this method to other laboratories with similar instruments, resulting in research publications.

The Neutron Physics Group has a substantial neutron detector development program, serving a wide variety of customers. Additionally, the group conducts research in prompt gamma activation analysis, which supports the construction materials and semiconductor industries, translating directly to several recent scientific publications. The research conducted in neutron interferometry, which is a unique application of physical measurement, has resulted in several publications in premier journals such as *Nature*, *Nature Physics*, and *Physical Review Letters*. From 2022 to 2025, the Neutron Physics Group performed 34 calibration services, published 33 scientific papers, and presented 19 invited talks. While the Neutron Physics Group uses several methods of measurement intercomparison, the manganese bath (a lynchpin for neutron

metrology) is the only device of its kind in the United States and could hinder productivity if damaged.

The Radioactivity Group disseminates output through research programs driven by stakeholder needs by creating Standard Reference Materials, maintaining standard reference databases, performing calibrations, contributing to guidance documents, and publishing research results. The Radioactivity Group consults and works with regulatory bodies, such as the Nuclear Regulatory Commission, the Environmental Protection Agency, and the Department of Energy, and provides calibrations for radiopharmaceutical providers, commercial laboratories, and nuclear power plants. Because each radionuclide requires its own standard, there is ongoing development of methods to characterize these materials, often resulting in scientific publications. Additionally, the direct development of novel radiation detectors is not only used to support internal NIST research such as the neutron beta-decay program but also shows promising results for a wide range of customer-driven applications.

The Radioactivity Group emphasizes its ability to leverage intercomparison methods developed at the laboratory, as well as in international, external comparisons. Specifically, several radionuclide standards have been evaluated with three or more comparative measurements to study discrepancies. From 2022 to 2025, the group created 865 Standard Reference Materials, provided 57 calibration services, produced 31 scientific publications, and presented 25 invited talks.

The RPD is unique among the other divisions of PML in that many of the calibration services it offers are mandated by federal regulation. These required calibrations necessitate high precision, robustness, and comprehensive techniques; NIST is often the only facility in the United States with the ability to provide these services. Its techniques lead to the development of methods driven by stakeholder needs. RPD's dissemination methods are effective and comprehensive in part because of their ability to conduct multiple intercomparisons, which greatly reduces systematic uncertainties. The division's research output is communicated effectively through journal publications that are appropriate for the work, often have a high impact, and are aligned with the NIST mission.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion 3-1: The Radiation Physics Division (RPD) of the National Institute of Standards and Technology's Physical Measurement Laboratory operates with varying levels of aging infrastructure. Specifically, there are underground laboratory and corridor areas that have sustained substantial water damage, and flooding can happen on a regular basis in the RPD building. There is evidence of flooding that significantly warped the flooring around a radioactive source. This flooring introduced tripping hazards and lacked structural integrity. Moreover, inadequate electrical infrastructure resulted in excessive use of extension cords. These issues not only pose several serious safety concerns but also hinder the staff's ability to do their work and conduct scientific measurements.

Recommendation 3-1: The leadership of the National Institute of Standards and Technology (NIST) Physical Measurement Laboratory should conduct a safety review of all Radiation Physics Division (RPD) laboratories and in collaboration with RPD and NIST leadership and the Office of Facilities and Property Management should establish a plan for flood and water damage mitigation and laboratory safety integrity.

Conclusion 3-2: National Institute of Standards and Technology (NIST) calibration services supplied to external stakeholders (e.g., Accredited Calibration Laboratories) are critical to the nuclear industry. There appear to be multiple occurrences where a single point of failure, due to either failing equipment or insufficient staff, in the Radiation Physics Calibration Program could potentially cause catastrophic delays to its external customers, who are required under Title 10 of the Code of Federal Regulations (10 CFR) Part 20 and 10 CFR Part 35 to use NIST-traceable radiation detectors.

Recommendation 3-2: The leadership of the National Institute of Standards and Technology Physical Measurement Laboratory and the Radiation Physics Division (RPD) should identify and stratify all mission-critical "single-point failures" in the RPD and implement remedies to those items. At a minimum, at least two people

PREPUBLICATION COPY—Uncorrected Proofs

should be trained to perform all instrument calibration work, and all radiation calibration-centric electronics used by the RPD should be examined and updated as needed. Additional staff may be required to ensure timely calibrations.

Conclusion 3-3: The current National Institute of Standards and Technology practice of funding only a few large research projects through the Innovations in Measurement Science funding mechanism appears to limit the number of potentially beneficial projects and inhibit the development of new projects.

Recommendation 3-3: The leadership of the National Institute of Standards and Technology Physical Measurement Laboratory should consider a funding mechanism that creates more opportunities to fund smaller innovative projects.

Conclusion 3-4: Internal purchasing processes have reportedly become sufficiently burdensome to counter their intended goal of controlling and reducing costs. Researchers reported that three quotes are needed to purchase an item, no matter how inexpensive that item is. The process of obtaining these quotes often results in a greater person-time cost than the cost of the actual items. Previously, some items were available through a centralized storeroom, which was phased out over the current purchasing process.

Recommendation 3-4: The leadership of the National Institute of Standards and Technology Physical Measurement Laboratory should consider establishing a threshold based on a cost analysis where items below a certain value do not require multiple quotes.

REFERENCES

- NRC (Nuclear Regulatory Commission). 1991. “Subpart F—Surveys and Monitoring.” *Federal Register* 56(98):23398. https://archives.federalregister.gov/issue_slice/1991/5/21/23349-23474.pdf.
- NRC. 2003. “Dosimetry Equipment.” *Federal Register* 68(76):19326. <https://www.govinfo.gov/content/pkg/FR-2003-04-21/pdf/03-9431.pdf>.
- PML (Physical Measurement Laboratory). 2025. Read-Ahead Material for NASEM Assessment of PML. National Institute of Standards and Technology, Gaithersburg, MD. Including updated actual obligated budget figures from Alan Thompson, National Institute of Standards and Technology.

PREPUBLICATION COPY—Uncorrected Proofs

4

Nanoscale Device Characterization

BACKGROUND ON THE NANOSCALE DEVICE CHARACTERIZATION DIVISION

The Nanoscale Device Characterization Division (NDCD) has assembled a strong team with world-class research and technical expertise. Five leadership teams oversee 13 major programs that address critical gaps in measurement science to support the domestic semiconductor industry; develop metrology for low-dimensional solid-state systems to advance quantum computing and sensing technologies; and establish fabrication methods, test structures, and instrumentation for characterizing nanoscale materials and devices. At the time of this assessment, the NDCD employed a total of 51 federal employees of which 9 were term employees, and more than 70 were associates.¹ In fiscal year 2025, NDCD had a budget of \$24.24 million, of which \$24.02 million were scientific and technical research services funds, \$222,000 were CRADA or other agency funds, and \$1,000 were other working capital funds² (PML 2025).

These programs span atom-scale devices, nanoscale spectroscopy, advanced electronics, nanoscale processes and measurements, and alternative computing. During the review process, program leaders delivered 13 presentations highlighting their progress and achievements in areas such as single-electron metrology; quantum anomalous Hall effect for metrology applications; spectroscopy and applications of solid-state quantum centers; analog quantum simulation; quantum electronics and photonics using silicon color centers; scanning probe metrology for quantum nanoelectronics; atom-scale device engineering, metrology, and manufacturing;

¹ Associates are domestic and foreign guest researchers from academia, industry, and other government agencies who collaborate on NIST research projects and use NIST facilities but are not NIST employees.

² Other agency funds are funding of NIST projects from other government agencies. Working capital funds include external reimbursable activity such as calibrations and internal reimbursable activity such as calibration operations and service development and standard reference material production and service development.

nanoscale thermal property mapping; advanced optical metrology; emerging power electronic devices; on-silicon metrology; hardware for artificial intelligence; and cryogenic electronics. The panel also participated in related laboratory tours.

TECHNICAL PROGRAMS

The quality of research in the NDCD is world class, overall. For example, in International System of Units (SI) realization and dissemination, researchers are involved in creating a new standard for the ampere, the SI unit of electrical current, based on the flow of single electrons through semiconductor nanostructures. This project has the potential to realize a new electrical current standard operating in a wide range of currents, with quantum technology applications. The NDCD is creating a new resistance standard that can operate at elevated temperatures and new magnetic field sensors that can be deployed in real-world conditions. Atom-by-atom manipulation and measurement of materials for potential SI standards is a world-class research thrust, with applications in devices for quantum applications, including analog quantum simulators based on individual phosphorous atoms in silicon. NDCD researchers are developing extremely precise and important measurement techniques to explore key features of modern nanoelectronic devices, such as thermal conductivity, optical characterization of critical dimensions, and failure mechanisms in power electronics devices. Applications of physical measurements are another focus, including the development of cryogenic electronics for quantum applications, and development of new power-efficient artificial intelligence (AI) chips and testing platforms for them. In particular, development of new electronics based on wide bandgap or ultra-wide band gap semiconductor materials could reduce computing power by an order of magnitude and be more tolerant to temperature swings experienced by computing devices deployed in AI applications. In total, these thrusts represent research directions that have major implications for both standards and technology and require extremely precise measurements, making National Institute of Standards and Technology (NIST) researchers very well qualified to address these goals.

The division is tackling topics with a large dynamic range from fundamental to applied. The division's activities are particularly thoughtful with respect to balancing core mission (measurement, standards, technique, and instrumentation development) with emerging programs

that address new national priorities, such as Quantum Information Science, Microelectronics, and AI. Examples of the former are the projects to define current and resistance standards with new materials and single-electron devices, propelling the state of the art in scanning probe microscopy by inventing new instrumentation, and building atom-scale devices. New initiatives and programs that respond to national priorities on microelectronics and enhance the impact of the division's research portfolio include inventing new techniques to map thermal conductivity at nanometer scales, developing extreme-ultraviolet optical metrology methods, and assembling a strong, multimodal project in connecting microscopic defects to device properties for power electronics. These projects represent an important research capacity aimed at translation and derisking technology that can have a big impact on problems in industry, highlighting the complementary role that NIST can play in the research ecosystem. They also serve as excellent examples of how to leverage collaborators from other organizational units, outside academic entities, and industry to achieve large-scale projects.

Complementarily, there are also emerging initiatives to explore new models for scientific collaboration and project scope that leverage the unique strengths of the Physical Measurement Laboratory (PML). First, the new effort on color centers in diamond that focuses on translational research for position, navigation, and timing is particularly well posed. The scope of the project—system architecture to improve size, weight, and power; devising precision measurement schemes for measuring the electron g-factor to establish traceability; and using machine learning techniques to optimize system performance and multiparameter estimations—is well suited to the NIST mission and leverages the strengths of PML. Second, the effort to provide open-source chip design and tape-out services as a testbed to enable emerging device technologies is an innovative model that can catalyze technology translation for emerging circuits and materials, and in turn can help NIST scientists refine their own understanding of the critical pain points in industry. The panel found that NDCD laboratories are well equipped and operated by highly competent technical staff, enabling effective execution of research aligned with PML priorities. In accordance with the statement of task, the panel concludes that the quality of the NDCD's research and technical programs is excellent.

SCIENTIFIC EXPERTISE

The scientific expertise in the NDCD is also world class, and it is extremely well suited to carrying out the mission and program objectives of PML. Formed in 2019 after a divisional realignment, the NDCD has historical roots in the semiconductor electronics group at NIST. As a result, the NDCD today has tremendous expertise in this and related areas, which it leverages to address overall PML objectives, from defining and disseminating the SI to quantum and AI applications. For example, the NDCD maintains a world-renowned group with expertise in scanned-probe microscopy. The division leverages this expertise to develop not only new ways to define and disseminate the SI (e.g., through improved understanding of two-dimensional materials that could be used for resistance standards), but also to create nanoelectronic devices with novel classical and quantum functionality, such as quantum simulators based on individual phosphorous atoms in silicon. The NDCD also harnesses its deep and long-standing expertise to address critical challenges in the manufacturing of modern computer chips. For example, division researchers are developing new ways to inspect the dimensions of lithographically defined features during processing, understand the dissipation of heat in nanoscale devices, and understand the mechanisms of failure in high-power transistor devices.

The NDCD's scientific expertise is very well aligned to and organized in support of NIST's goals. As discussed in the previous section, nearly all the projects align with multiple PML priorities, including defining and disseminating the SI, advancing quantum science, and developing AI technologies. While each of these research spaces is large and highly competitive, the NDCD has chosen high-impact problems that allow its researchers to leverage their expertise. One example of such a strategic choice is the project on cryogenic electronics for quantum applications. While multiple commercial and academic groups are also working in this space, most are working on cryogenic control electronics for quantum devices. NIST researchers have chosen to focus on characterizing potential cryogenic electronic devices for not only control, but also readout, a much more demanding application because it involves amplification and heat generation. This is an excellent example of a "NIST hard" challenge—a problem that demands measurements so precise that few other groups in the world besides NIST could attack it. The division director has done an admirable job of balancing different research priorities and identifying key research opportunities for the scientists and capabilities in the division.

PREPUBLICATION COPY—Uncorrected Proofs

A challenge for the division in the years ahead will be to maintain the required scientific expertise in the face of retirements and changing program goals. Active succession planning and onboarding of early-career researchers will continue to be important in the coming years. In meetings with the panel, early-career researchers noted the collegial atmosphere of NIST and the opportunity to learn from world-class, highly visible scientists who continue their active engagement in research throughout their careers. Early career researchers also noted the appealing combination of fundamental and applied science that takes place in the division, the possibility of starting new projects, and the potential for stable, long-term employment.

A steady flow of associates will also be essential for continued success of this division's mission. The NDCD and PML have historically relied on attracting the best talent from all over the world to carry out their science and engineering objectives. Keeping this pipeline open in the coming years will be essential for NIST, PML, and the NDCD to continue executing its mission.

FACILITIES, EQUIPMENT, AND HUMAN RESOURCES

In general, the facilities, equipment, and instrumentation of the NDCD are world class. Notably, the division has several projects that are meaningfully advancing the state of the art in instrumentation with customized designs and one-of-a-kind experimental apparatuses, particularly in scanning tunneling microscopy, extreme-ultraviolet optical techniques, and photothermal-induced resonance microscopy. The division has made good strategic investments in new laboratory facilities and equipment, and it has a healthy process for defining priorities and planning for equipment purchases. Its long-term vision in infrastructure and equipment investment enables transformative work—one example is the scanning probe microscopy instrumentation that spans four decades with the newest addition of SPM VI under ultrahigh vacuum and operating at 10 mK, brought online in 2025.

However, the underlying building facilities have serious problems, as detailed many times throughout this report. Frequent power outages (planned and unplanned downtime for facilities maintenance); water main leaks; poor heating, ventilation, and air conditioning control; and other infrastructure issues place fulfillment of the central mission of the division at risk. These could also pose a safety risk, as staff may attempt to make repairs without adequate safety training. To push the state of the art in metrology, the NDCD scientists must also have state-of-

the-art technical infrastructure. Similarly, vacancies in the management and administration of the NDCD pose an obstacle to the effective functioning of the group.

EFFECTIVENESS OF DISSEMINATION OF PROGRAM OUTPUTS

The NDCD has demonstrated strong effectiveness in disseminating program outputs. Its efforts focus on advancing measurement science and fundamental knowledge essential for characterizing nanoscale and atom-scale engineered materials, as well as solid-state devices supporting innovation in information processing, sensing, and future quantum technologies. Dissemination activities include publications in high-impact, open-access journals (e.g., *Nature Communications*, *PRX Quantum*, *Nano Letters*) and invited presentations at national and international conferences and workshops.

NDCD researchers collaborate extensively—both within NIST and with external partners—leveraging their expertise to secure external funding and increase the visibility and impact of their work. Additional dissemination channels include technology transfer, patent applications, and partnerships with universities and industries. The NDCD laboratories also host tours for visiting researchers and policy makers to broaden the program’s impact. Since the last assessment in 2021, the NDCD has reported 19 invention disclosures, 21 patents (15 granted, 6 pending), 2 licenses, 10 Cooperative Research and Development Agreements, and a total of 237 publications.

The division and its leadership take a thoughtful approach to understanding and anticipating stakeholder needs. They recognize the critical role of industry in defining new research problems while balancing this input with forward-looking ideas that hold the potential for transformative impact. A notable initiative is the Integrated Testbeds program, an open-access complementary metal-oxide-semiconductor platform for emerging technologies, which provides an open-source tape-out sponsored by a corporate partner. This platform has strong potential as a resource for enabling research by start-ups and universities.

NDCD scientists maintain high visibility and stature in their fields; however, recent travel restrictions pose risks to sustaining this leadership role. Continued support for external engagement will be critical to maintaining their position of influence within the broader research community.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion 4-1: The leadership of the Nanoscale Device Characterization Division has done an excellent job in balancing the core mission of the National Institute of Standards and Technology while also making progress toward application-driven goals. Most of the projects in the division support multiple Physical Measurement Laboratory goals, such as defining and disseminating the International System of Units, quantum science, and artificial intelligence.

Conclusion 4-2: The Nanoscale Device Characterization Division has improved its collaboration with industry, as recommended in the previous National Academies report. Collaboration with industry has enhanced both the scientific and application-oriented research in the division. Industrial collaboration has also enhanced the public impact of the division through both commercial applications and the development of trusted standards.

Conclusion 4-3: The scientific output of the Nanoscale Device Characterization Division is world class. This record of publications and talks is essential for recruiting and retaining exceptional talent in the division.

Recommendation 4-1: The leadership of the National Institute of Standards and Technology Physical Measurement Laboratory and the Nanoscale Device Characterization Division (NDCD) should ensure that NDCD scientists are able to disseminate their results and communicate with their research communities in government, academia, and industry robustly, particularly through conference and workshop travel and follow-up conversations with the identified experts.

Recommendation 4-2: The Physical Measurement Laboratory leadership in collaboration with the Nanoscale Device Characterization Division and National Institutes of Standards and Technology leadership and the Office of Facilities and Property Management should prioritize maintenance and operations actions that ensure that the facilities and infrastructure problems do not endanger the core scientific mission.

PREPUBLICATION COPY—Uncorrected Proofs

REFERENCE

PML (Physical Measurement Laboratory). 2025. Read-Ahead Material for NASEM Assessment of PML. National Institute of Standards and Technology, Gaithersburg, MD. Including updated actual obligated budget and staffing figures from David Gundlach, National Institute of Standards and Technology, March 25, 2026.

PREPUBLICATION COPY—Uncorrected Proofs

5 Quantum Measurement

BACKGROUND ON THE QUANTUM MEASUREMENT DIVISION

The Quantum Measurement Division (QMD) provides foundational metrological infrastructure for the United States, with a particular emphasis on the International System of Units (SI) realization, the SI dissemination, and quantum science. As part of this work, the QMD realizes and supports several SI units, provides calibration services, conducts research into atomic and quantum physics, and innovates new measurement methods and quantum-based technologies. The division is organized into groups on Atomic Spectroscopy (not covered in this assessment as it is slated for closure), Quantum Optics, Laser Cooling and Trapping, Fundamental Electrical Measurements, Applied Electrical Metrology, and Mass and Force. This division also collaborates with the University of Maryland through the Joint Quantum Institute to advance quantum science in areas such as quantum computation and simulation.

The breadth of the division is demonstrated in its leadership in quantum science, its pioneering techniques in mass and force, and its participation in national policy across the federal government. Its impacts are demonstrated in the number of publications, Cooperative Research and Development Agreements (CRADAs), and patents and licenses generated by the division as well as the QMD staff's participation in global documentary standards committees. The QMD undertakes about 77 types of calibrations, with 5,502 calibration tests performed over the past 4 years totaling \$6.4 million. The division had a total of 265 publications across 87 journals with 346 co-author affiliations, and its papers had 3,099 citations since 2021 at the time of the assessment. Its technology transfer metrics included 5 CRADAs, 61 invention disclosures, 43 patents (13 granted, 30 pending), and 6 licenses in the past 4 years. At the time of this assessment, the QMD employed approximately 100 employees, of which approximately half

were federal employees and half were associates.¹ In fiscal year 2025, QMD had a budget of \$33.29 million, of which \$26.74 million were scientific and technical research services funds, \$4.12 million were other agency funds and \$2.01 million were Measurement Services funds, and \$437,800 were Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act funds² (PML 2025).

TECHNICAL PROGRAMS

The QMD's accomplishments cover a wide spectrum. The Laser Cooling and Trapping Group (LCTG) broadly explores science at the intersection of atomic, molecular, and optical physics, condensed-matter physics, and quantum information science, using both experimental and theoretical approaches. This group includes some of the most prominent research teams in the world, pioneering techniques of laser cooling and their application to various problems in metrology. Additionally, they have further expanded into areas of quantum simulation. The combination of expertise and the resulting expansion has allowed them to define a new and active subfield with transformational effects on our understanding of quantum systems: large and small, in and out of equilibrium, open and closed. A substantial portion of this division's work, done in collaboration with researchers through the Joint Quantum Institute and the University of Maryland, leads to a dynamic research environment and culture, combining traditional strengths of academia with those of a federal laboratory. The success of this group is clearly evidenced by a robust and high-impact publication record, placement of early-career staff into prominent positions in academia, government, and industry, and awards and accolades of many members of the group ranging from high-school interns to a Nobel Prize winner (and reflecting a characteristic "full-spectrum" commitment to excellence and mentorship in the group). Multiple high-value U.S. companies have been launched utilizing technical breakthroughs developed in part by this group.

Compelling ongoing research in this group includes inquiries of critical industrial significance, most prominently for quantum computing, communication, and sensing,

¹ Associates are domestic and foreign guest researchers from academia, industry, and other government agencies who collaborate on NIST research projects and use NIST facilities but are not NIST employees.

² Other agency funds are funding of NIST projects from other government agencies. Working capital funds include external reimbursable activity such as calibrations and internal reimbursable activity such as calibration operations and service development and standard reference material production and service development.

specifically on weak measurement of quantum degenerate gases, autonomous cooling of qubits, and engineered Rydberg interactions in cold atoms. These studies are timely, and track tightly with critical technology development of national and worldwide significance, providing insight into important phenomena that crosscut many competing approaches aggressively developed for quantum technologies by industry and other sectors.

The Quantum Optics Group is leading the single-photon-sources development for quantum networks. The dictionary for single-photon sources and detectors, first published in 2023 and then revised in 2025, is an important first step in standardization for the quantum community. The report, an outcome of a National Institute of Standards and Technology (NIST)-led Quantum Economics Consortium workshop, is an excellent example of response to stakeholder needs. The group is an active participant in the Washington Metropolitan Quantum Network Research Consortium, a network testbed to evaluate components and protocols. Efforts in quantum network development include demonstrating coexistence of quantum and classical signals, subpicosecond timing synchronization, and next-generation telecommunication-compatible single-photon sources.

As described in the 2021 National Academies report, a notable accomplishment of the Fundamental Electrical Measurement Group has been the development of the Kibble balance for the primary realization of mass (NASEM 2021). The impressive work of the group has led to the redefinition of the kilogram in terms of the Planck constant. The official SI redefinition on May 20, 2021, is noted along with the ongoing use of the consensus value arising from disagreement between the two leading measurements (the Avogadro project at Physikalisch-Technische Bundesanstalt, Germany, and the Kibble balance at the National Research Council-Canada). With the NIST-4 Kibble balance, measurement of the Planck constant and subsequent realization of the kilogram are carried out with remarkable accuracy (<10 ppb) once evaluation of the different magnetic coils is complete, currently comparable to other world leaders in this sector (Haddad 2025). Ongoing collaborations are under way with the Physikalisch-Technische Bundesanstalt in Germany and the Research Institutes of Sweden (RISE) to compare measurement of standards at different institutes and decrease uncertainty. In the collaboration with the Research Institutes of Sweden, PML demonstrated the quantum metrology triangle through the implementation of the quantum Hall resistance array in the measurement circuit of their Kibble balance. Since the 2021 National Academies review, QMD has made laudable

PREPUBLICATION COPY—Uncorrected Proofs

progress in establishing the Quantum Electro-Mechanical Metrology Suite. The group also leveraged a nascent CRADA with industry to deploy small-scale calibration systems (versions of KIBB-g2 and subsequent revisions). Based on the Kibble balance, PML is successfully establishing and transitioning table-top standards for mass and torque to industry (e.g., Snap-on) and the Department of Defense establishments (e.g., U.S. Army TMDE Activity (USATA) Primary Calibration Laboratory at Redstone Arsenal, Nellis Air Force Base). There is also a growing portfolio of PML patents filed stemming from this division's work. Overall, this transition work has been outstanding and has tremendous potential for impact, which is expected to see further growth in the future.

The Applied Electrical Metrology Group (AEMG) performs foundational research to create deployable, multifunction quantum electrical standards. They aim to improve the dissemination of SI by creating tools and techniques that increase the efficiency and user-friendliness of quantum standards. The group supports the nation through calibrations of alternating current (AC) voltage and direct current (DC) voltage, AC current ratio, as well as AC-DC difference, electric power, and phase angle. The AEMG has a strong technical program that meets its objectives and is competitive with other National Metrology Institutes' (NMIs') research. The group is working on a unified quantum electrical realization to combine the quantum Hall resistor with a Josephson voltage standard to provide direct traceability for Ohm's law in one system. The significant impact of this work will be extremely beneficial for primary standards laboratories throughout the nation, lauded in press coverage as a "one box" electrical standard that is more deployable and less complex (Underwood et al. 2025). The group is focusing on improving the user's experience for the Josephson Arbitrary Waveform Synthesizer to improve automation of optimization of the system. The group is developing a new nanophotonic thermal transfer device that aims to reduce the uncertainties for AC-DC difference through accurate comparison of AC and DC joule heating.

Technical contributions within the Mass and Force Group display an excellent combination of core calibration services in conjunction with the metrological scientific advances. This group works closely with the Fundamental Electrical Measurement Group to take the realization of the kilogram from the Kibble balance and disseminate that throughout their world-leading mass and force capabilities spanning more than 14 orders of magnitude (e.g., 10 micronewton resolution for the electrostatic force balance to meganewtons in the million pounds-

force deadweight machine). Exemplifying one of the numerous pioneering measurement techniques conceived and fabricated within the Mass and Force Group is the refractive index sound standard, which enables a direct calibration of microphones across a variety of acoustic devices, instead of the traditional comparison method that is only as good as the reference microphone. Microphones are key in nuclear testing, sound-level safety analysis for work sites, and more.

SCIENTIFIC EXPERTISE

The different groups have the appropriate level of scientific and engineering staff to deliver on their mission. In particular, the technical caliber of the QMD staff, associates, and visiting scientists is excellent. Many of the staff members received one or more prestigious awards during their service, with examples being the NIST Gold Medal and PML Distinguished Associate Awards. Junior staff members have also received multiple early-career scientist awards and have been awarded multiple fellow appointments with various organizations.

Over the past several years, members of the QMD routinely made substantial, and even essential, contributions to national policy leadership and direction through details in the Office of Science and Technology Policy and the National Science Foundation, representing an important contribution of the group. After recent changes at the federal level, this share of voice has been diminished; the QMD should strive to continue its tradition of serving as a resource within new and emerging national science initiatives and policies.

The LCTG currently has five principal leaders, all of whom are recognized worldwide as top contributors to their field of laser-cooled atomic gases and together bring expertise across the group's mission and program objectives, including one Nobel laureate and prominent members of national science policy organizations. Two recent departures of senior leaders have resulted in gaps in expertise, and a significantly improved outlook for future work could be ensured by high-level recruitment in quantum optics and single- or few-atom quantum control scientists to replace these competencies and react to the emerging interests within U.S. industry.

Similar to the LCTG, departures of key members of the Mass and Force Group have the potential to jeopardize the turnaround time and quality of mass and force calibrations routinely utilized by U.S. industry and other government laboratories, and full participation on the national

stage with other NMIs. Compounding the above issue, key members are reaching retirement age, which makes succession planning even more critical. Departure of further staff in this area could require replacing missing capabilities needed to maintain the necessary quality and throughput. Bolstering the calibration side of this group with one or two early-to-mid-career scientists would ameliorate negative consequences of departures within the group over the next decade.

FACILITIES, EQUIPMENT, AND HUMAN RESOURCES

The QMD has demonstrated remarkable research and calibration output since the last review in 2021, despite facing significant challenges in 2025 owing to hiring freezes and anticipated decreases in future funding. These resource constraints jeopardize the operation of aging facilities, which are crucial for maintaining the division's high standards.

Unique facilities, such as the Quantum Electro-Mechanical Metrology Suite that houses the Kibble balance, benefit from the dedication of laboratory staff who work diligently to minimize downtime. For instance, due to HVAC malfunctions, NIST staff often come in during off hours to perform calibrations when environmental conditions meet the necessary specifications for temperature and relative humidity. However, NIST calibration services are increasingly struggling to compete on cost with other NMIs that may benefit from additional government subsidies, allowing them to offer lower prices. Currently, the staff levels are at a minimum required to maintain the existing calibration workload, which hampers efforts to enhance services and advance scientific research.

The AEMG possesses strong expertise but has faced numerous retirements in recent years without successfully backfilling those positions. With only four staff members currently, it is essential to recruit additional personnel to support the group's mission effectively. As noted in the 2021 report, the group lacks sufficient staffing to meet calibration demands and to provide multijunction thermal converter standard reference instruments to its customer base (NASEM 2021). While the equipment is adequate for the organization's missions, persistent facility issues, such as problems with processed chilled water and electromagnetic interference, often lead to measurement inaccuracies and instrument downtime.

Facilities for the LCTG and Quantum Optics Group, built in 2006, represent some of the most recent infrastructural investments on the Gaithersburg campus. Although the laboratories

are reasonably modern and well designed, the core performance of the building envelope does not align with its age, and environmental control systems frequently fail, limiting productivity. Moderate investments in building improvements, compared to other groups in the division, are likely warranted and could yield significant returns through increased calibration and experimental uptime.

Considering these challenges, the QMD has made the difficult decision to retire the Atomic Spectroscopy Group this year. Additionally, backfilling aging staff in precision metrology remains a challenge, as this specialized work requires 4–5 years of training. The division plans to rely on PML’s succession planning budget as needed, although it may not be sufficient to meet the long-term needs of these critical groups.

EFFECTIVENESS OF DISSEMINATION OF PROGRAM OUTPUTS

Dissemination of outputs is a key priority for the division. The methods include physical media and instrumentation transfer, publications in peer-reviewed journals and conference presentations, patent applications, software for facilitating operation of instrumentation and data analysis, as well as various databases.

The QMD has published 265 publications over the past 4 years in journals such as *Physical Review Letters*, *Physical Review A*, and *PRX Quantum*. They generated 5 CRADAs with different companies, 43 patents (13 granted, 30 pending), and 6 licenses. They performed 5,502 customer calibrations which have had a significant impact for the nation, with one example being approximately 6 calibrations per year at NIST transforming into more than 300,000 calibrations performed by the state metrology laboratories every year (NCSLI 2024). Approximately one-third of the QMD’s staff serve on or lead documentary standards committees, which have a significant impact on the global metrology community. These documentary standards range from applied metrology via the International Measurement Confederation (IMEKO) to the International Atomic Energy Agency, which is the leading cooperative platform for nuclear applications such as energy and medicine.

Other revolutionary approaches to dissemination of the SI stem from the development of the electrostatic force balance (EFB), which utilizes the same principles as the Kibble balance but operates in a completely different mass and force regime (submilligram and

submicronewton). In addition to the obvious application to mass and force calibrations, such as achieving a 10-fold improvement in uncertainty for 1 mg calibrations, the advancement has enabled ongoing work toward providing mass references for micrometer-sized particles containing rare earth or transition metal elements necessary to create 21st century electronics. The scientific creativity and rigor of the EFB team extended its application to numerous nonobvious, yet essential, areas such as the calibration of atomic force microscopy (AFM) cantilevers that are ubiquitous for characterization of new materials and realization of the optical watt via in situ measurement from a mirror attached to the EFB. As noted in the 2021 review as well, the establishment of the Quantum SI, and in particular the introduction of the new mass standard in terms of the Planck constant, has been accompanied by an outstanding range of outreach and educational activities, including in particular the NIST do-it-yourself LEGO® Kibble balance, which permits a broad audience of students and science enthusiasts to build their own working Kibble balances out of LEGO® bricks. Staff from QMD created productive engagements with industry and the Department of War (DOW), which led to wider use of the table-top Kibble balance for both mass and torque measurements.

With the closure of the Atomic Spectroscopy Group, the web-based databases of spectral lines, energy levels of atoms and ions, ionization energies, and an extensive bibliography of the sources are no longer updated. These resources are instrumental for research in atomic physics and spectroscopy conducted by major stakeholders: Department of Energy and DOW laboratories, the National Aeronautics and Space Administration, academia, and industry. It is of paramount importance for NIST to maintain close collaboration with the Joint Quantum Institute to continue providing access to these atomic data. However, recent advances in several areas of research require extending the range of available data, with a few examples needed for EUV lithography targets being gadolinium, bismuth, and other high-Z elements which often have complex electron energy level structures. The ability to benchmark *ab initio* calculations and atomic simulations against accurate, validated sets of data is extremely valuable. Existing databases, however, do not contain the data for relevant ionization stages. Updated databases would provide crucial information for the development of the radiation sources and optical components helping to maintain U.S. leadership in the semiconductor business.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion 5-1: The Quantum Measurement Division demonstrates world-class calibration and research capabilities. It is critical to the core National Institute of Standards and Technology (NIST) mission of realizing and disseminating the International System of Units (mass, force, ampere) which underpins nearly every commercial product in the United States. The teams actively engage with international counterpart National Metrology Institutes to seek consensus and improve NIST's state-of-the-art calibration systems, while working with partners to adapt these systems for wider adoption. While the equipment is adequate for the organization's missions, persistent facility issues, such as problems with processed chilled water and electromagnetic interference, often lead to measurement inaccuracies.

Recommendation 5-1: The National Institute of Standards and Technology (NIST) Physical Measurement Laboratory should collaborate with the Quantum Measurement Division and NIST leadership, and the Office of Facilities and Property Management to continue to pursue facilities upgrades from deferred maintenance (e.g., flood prevention, better humidity control), as the ongoing facility issues drastically impact calibration turnaround times and equipment uptime. The Quantum Measurement Division should consider expanding its use of dedicated technical staff (currently a single engineer who interfaces with the NIST facilities group) to maintain its specialized facilities needed for calibration of equipment and groundbreaking research.

Conclusion 5-2: Quantum Measurement Division staff provide critical voices for defining the country's national quantum initiative strategy and continually generate excellent research in the field of quantum simulation, quantum thermodynamics, and single-photon sources. As the quantum science and technology ecosystem grows, clarifying the National Institute of Standards and Technology's role in the next 5 years will become more important.

Recommendation 5-2: The Quantum Measurement Division (QMD) leadership should create a communication plan with clear industry-relevant metrics that shows how its research and calibrations have positively impacted U.S. commerce. Such a proactive initiative should spearhead further engagement with industry to identify emerging needs in standards and metrology and enable collaborative updates to existing databases and reports. The leadership of the Physical Measurement Laboratory and the QMD should ensure that valuable databases, such as the one assembled and maintained by the former Atomic Spectroscopy Group, are retained and remain available to government and industrial entities.

Conclusion 5-3: The Quantum Measurement Division (QMD) exhibits high engagement with academic collaborators, especially with the University of Maryland through the Joint Quantum Institute. High-profile publications, especially in metrology, show the continued relevance and quality of the research. In 2025, the QMD lost significant senior staff, both through incentivized early retirement and through transfer to other parts of government. The combination of the Physical Measurement Laboratory's succession planning fund, reinstatement of the National Research Council postdoctoral program, and its plan to backfill currently open positions is critical for maintaining the current level of success at producing scientific achievements needed to enable the precision calibration services the National Institute of Standards and Technology provides that underlie the U.S. economy.

Recommendation 5-3: The Quantum Measurement Division (QMD) should collaborate with other Physical Measurement Laboratory divisions (in both Gaithersburg and Boulder) to formulate a unified strategic approach in quantum technologies (communication, sensing, and computation) and identify a select set of distinctive capabilities that leverage their unique metrology expertise. The QMD should prioritize activities both within and beyond its current expertise, identifying underrepresented areas and organizational weaknesses in critical national technologies, and articulating pathways to address these gaps, including redistribution of efforts between divisions.

REFERENCES

- EUV Litho. n.d. “Blue – X.” EUV Litho, Inc. <https://euvlitho.com/blue-x>. Accessed December 19, 2025.
- Haddad, D. 2025. “NIST Primary Realization of Mass via Kibble Balances.” Presentation to the committee. September 9. Gaithersburg, MD.
- NASEM (National Academies of Sciences, Engineering, and Medicine). 2021. *An Assessment of Selected Divisions of the Physical Measurement Laboratory at the National Institute of Standards and Technology: Fiscal Year 2021*. Washington, DC: National Academies Press. <https://doi.org/10.17226/26312>.
- NCSLI (National Conference of Standards Laboratories International). 2024. State Laboratory Program Workload Survey. NCSLI 156 Legal Metrology Committee. <https://www.nist.gov/system/files/documents/2025/06/17/2024%20SLP%20Workload%20Survey.pdf>
- PML (Physical Measurement Laboratory). 2025. Read-Ahead Material for NASEM Assessment of PML. National Institute of Standards and Technology, Gaithersburg, MD. Including updated actual obligated budget figures from Gerald Fraser, National Institute of Standards and Technology, March 25, 2026.
- Underwood, J., B. Waltrip, and Z. Barcikowski. 2025. “Quantum Waveform Metrology.” National Institute of Standards and Technology. <https://www.nist.gov/programs-projects/quantum-waveform-metrology>.

6 Sensor Science

BACKGROUND ON THE SENSOR SCIENCE DIVISION

The Sensor Science Division (SSD) is responsible for dimensional, thermodynamic, optical radiation, and fluid flow measurements traceable through the National Institute of Standards and Technology (NIST) to International System of Units (SI) units via calibrations, standards, and new measurement solutions. The division performs 43.7 percent of NIST’s total calibrations (by revenue), several of which underlie other SI-unit calibrations within and outside of NIST. The division supports the U.S. role in global metrology for the realization and dissemination of three of the seven base units of the SI: the meter, kelvin, and candela. In addition to the technical capabilities, the SSD operates under a self-assessed quality system compliant with International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) 17025 (Test and Calibration Laboratory Management System), ISO/IEC 17034 (Reference Material Producer), and ISO/IEC 17043 (Proficiency Testing), additionally offering Quality Assessments and Peer Reviews. The SSD maintains connections to other National Metrology Institutes (NMIs) through NIST involvement in the Inter-American Metrology System and as a signatory to the International Committee for Weights and Measures Mutual Recognition Agreement. At the time of this assessment, the SSD employed a total of 101 staff, of which 75 were federal employees and 26 were associates.¹ In fiscal year 2025, SSD had a budget of \$34.08 million, of which \$25.80 million were scientific and technical research services funds, \$4.69 million were other agency funds, and \$3.59 million were other working capital funds² (PML 2025).

The division’s technical programs serve a wide range of stakeholders, including government and industry. Focus areas include measurement services and standards development; large- and small-scale dimensional metrology and surface structure; radiometry, photometry, and

¹ Associates are domestic and foreign guest researchers from academia, industry, and other government agencies who collaborate on NIST research projects and use NIST facilities but are not NIST employees.

² Other agency funds are funding of NIST projects from other government agencies. Working capital funds include external reimbursable activity such as calibrations and internal reimbursable activity such as calibration operations and service development and standard reference material production and service development.

optical properties of materials; and pressure/vacuum, temperature/humidity, and flow/liquid volume. The division counts its benefits to industry, government, and society via the use of its standards and calibrations. These underlie millions of dollars of commercial transactions, billion-dollar industries, critical international research infrastructure, national defense systems, and health systems. However, the SSD faces significant challenges owing to aging infrastructure and outdated equipment. This review highlights strengths and challenges across technical programs, scientific expertise, resources, and output dissemination, while providing recommendations aimed at maintaining high relevance and maximizing national impact.

TECHNICAL PROGRAMS

The SSD carries out some of the most advanced, next-generation SI-traceable measurements in dimensional metrology, thermodynamics, optical radiation, and fluid flow. The SSD delivers world-class calibrations, standards, and innovative measurement solutions that help U.S. industry stay competitive in the global market by dissemination of SI traceability throughout the product life cycle (i.e., product development, manufacturing, service, and product end of life).

The SSD calibrates approximately 700 test articles per year across a very diverse customer base including industry, accredited laboratories, academia, and various federal government agencies such as the Department of War (DOW), the National Aeronautics and Space Administration, the Department of Energy (DOE), and the Food and Drug Administration. In terms of revenue, the largest sector of calibration customers is DOW and its calibration laboratories (34.5 percent), followed by instrument manufacturing (16.5 percent), other manufacturing (12.6 percent), DOE (9.1 percent), aerospace (8.6 percent), other calibration laboratories (7.9 percent), and energy (5.8 percent), with several other industries represented as smaller fractions. The SSD utilizes a Measurement Services Dashboard (a customer relationship management software-derived tool) that provides both operational and customer-facing metrics, allowing the leadership to track customer experience and identify potential opportunities for operational improvement.

The SSD is comprised of seven groups, each having a specific mission in the realization and dissemination of the SI as well as providing research in the advancements of measurement

methods and traceability. The groups are Temperature and Humidity; Fluid Metrology; Optical Radiation, Photometry, and Remote Sensing; Fundamental Thermodynamics; Dimensional Metrology; and Surface and Interface Metrology. The Temperature and Humidity Group is dedicated to the realization of the temperature SI unit of measure through the application of traditional standards including triple point cells, as well as advanced temperature sensor research applying Doppler and silicon photonic thermometer approaches. The Fluid Metrology Group provides the realization and dissemination of the SI of gas flow, airspeed, and liquid flow. The standards and measurements maintained by this laboratory are very dependent on other laboratories within the SSD, including thermometry and dimensional metrology. This co-dependence builds strong cross-organizational partnerships as well as the potential for cross-disciplinary experience and training. The Optical Radiation, Photometry, and Remote Sensing Group maintains and advances primary standards and measurement research in radiometric and photometric capabilities in the measurement of optical power, irradiance, and radiance across a broad wavelength spectrum including ultraviolet through visible light and into infrared. The Fundamental Thermodynamics Group has realized the pascal, the SI unit of pressure, for many decades through classical primary standards, and, as with other SSD laboratories, provides cutting-edge research in quantum-based realization methods. The Dimensional Metrology Group realizes and disseminates the SI unit of length, through the application of optically based interferometric and traditional tactile measurement methods. This laboratory provides calibration and measurement services of traditional dimensional standards (such as gage block and step masters) but also provides ancillary measurement services including derivation of the temperature coefficient of materials. The Surface and Interface Metrology Group provides calibrations of transfer standards for surface roughness, step height, lateral spacing, and microform geometry. This laboratory's work ties closely into the work in the Dimensional Metrology laboratory in application of length in the measurement of surface roughness and form.

The quality of calibrations and research programs is comparable to or exceeds that of other leading NMIs (e.g., the United Kingdom's National Physical Laboratory, Mexico's Centro Nacional de Metrología, and Germany's Physikalisch-Technische Bundesanstalt). The SSD's laboratories have benefited through their involvement in regional and global NMI organizations, providing opportunities for bidirectional benchmarking and cooperative research. That said, the critical element of maintaining these types of working relationships depends greatly on the

PREPUBLICATION COPY—Uncorrected Proofs

recognized technical skills of the staff and the facilities and technology applicable to their work. Continuous improvements of the SSD's capabilities will be tied to maintaining an appropriate level of experienced staff and world-class facilities and equipment.

The SSD has established a diverse portfolio of calibrations and research programs. Defense and semiconductor applications are heavily represented in both calibration activities and the research portfolio. In the case of defense, this prominence reflects its role as both the largest calibration customer and a primary external sponsor of SSD research. The advances in foundational and applied measurement research and in calibration services developed in SSD are applicable across a wide range of sectors, including reduced uncertainties, expanded measurement ranges, new calibration methods, and new operational services. However, a strong focus on the needs of the current customer base may limit opportunities to develop new measurement science and services tailored to other emerging or underserved industries. For example, standards remain underdeveloped for various vector quantities relevant to agricultural sensing. Collaborative efforts to establish such standards could create new pathways for SSD engagement in that sector. Similarly, in advanced and heavy manufacturing, gaps persist in measurement capabilities related to in-process sensing, large-scale dimensional metrology, and harsh-environment measurements. Calibration of part-like masters is another gap in precision machining. Targeted research and standards development in these areas could enable SSD to better support manufacturing productivity, quality assurance, and process control. Compared to defense and semiconductor stakeholders, there is limited evidence of targeted application and structured engagement applying SSD's services to these additional sectors.

SCIENTIFIC EXPERTISE

The highly skilled and experienced workforce significantly contributes toward the success of the SSD. The SSD staff have a very diverse educational and professional background spanning several industries and technical fields, with a common goal of providing world-class measurements and traceability. As a result of their specialized technical backgrounds and expertise, the SSD staff are routinely engaged with various professional standards-writing bodies, including the American Petroleum Institute, the American Society of Mechanical Engineers, the Illuminating Engineering Society, and the ISO. In addition to their consensus

PREPUBLICATION COPY—Uncorrected Proofs

standards work, the SSD staff have produced 333 publications over the past 4 years, including publications in journals such as *Metrologia*, *Nature Communications*, and *Astrophysical Journal*, invention disclosures, and patents. To further support knowledge transfer, the staff lead subject-matter-expert workshops on a periodic basis, including representatives from various industries, academia, and U.S. government agencies.

The SSD has determined that the long-term tenure of its staff presents a short- and mid-term risk to maintaining its level of scientific expertise. A large proportion (approximately 40 percent) of the scientific staff are eligible for retirement. The SSD leadership has instituted a mentorship program for “emerging professionals,” providing a proactive way to fill future staff needs stemming from employees reaching retirement age. This program enables continuity with an ongoing investment in early-career development and knowledge transfer. It helps to reduce risk to interrupting services to their customers.

The SSD leadership provides strong support for technical programs, ensuring alignment with the laboratory’s mission. The SSD staff are experts in their respective scientific fields, with credible achievements, including board memberships and major scientific awards. The staff expertise is focused on the current technical priorities of defense and semiconductor industries. There is limited expertise in the measurement needs and advanced technologies in other industries, such as advanced manufacturing and agricultural sensing. Outreach and partnership development with universities, commercial laboratories, or consortia could allow the SSD to obtain expertise in emerging technical needs.

FACILITIES, EQUIPMENT, AND HUMAN RESOURCES

The primary funding provided through PML budgets and services to customers is insufficient to fully support the operations; equipment repair, purchase, and upgrading; and infrastructure needs of the division. The current SSD research funding model is supported by external sponsors, with the DOW serving as the primary source. Other sectors could become increasing customers of SSD’s calibration services or external funders of research, and thus new funding streams; however, engagement with those industries is currently less developed than with defense and semiconductor stakeholders, limiting opportunities to increase awareness of existing services or to develop new services informed by sector-specific needs. Working with

strategic planning or business planning experts, including via a model of external facilitators and expert panels formed from targeted new customers, could help the SSD take advantage of new opportunities.

Even with new funding streams for facilities operation, funding for repair, upgrading, and replacement of equipment may remain challenging. Examples of such antiquated equipment hindering performance include aged heat sources (furnaces and temperature baths) that require a large amount of manpower to keep running. There are instances where newer equipment is available, but the application is limited to a specific project or customer base, potentially driving lower equipment utilization. This hinders the SSD in advancing measurement science and delivering timely calibration services. Facility infrastructure challenges also hamper the work of the SSD. Heavy plastic taped to the ceilings to avoid equipment damage from flooding, uneven flooring panels causing tripping hazards, and temporary heating, ventilation, and air conditioning systems used to supplement nonfunctional central environmental systems highlight infrastructure and facility conditions. Aging facilities and outdated equipment hinder productivity and innovation. Prioritizing infrastructure upgrades will improve service delivery, research output, and the organization's ability to attract new partnerships.

EFFECTIVENESS OF DISSEMINATION OF PROGRAM OUTPUTS

The organization has a strong national and international presence. As earlier stated, the SSD disseminates research outputs primarily through established standards, calibration services, and direct stakeholder engagement (such as through Cooperative Research and Development Agreements). The division has demonstrated industry leadership in SI realization and dissemination, measurement and calibration services, and measurement research. Ongoing collaboration with professional societies, NMIs, and selected industry partners is critical to meeting the SSD's vision and mission goals. The SSD could benefit from additional outreach and research collaborations with sectors such as advanced manufacturing and agricultural sensing, to augment and diversify work that is currently focused on defense and semiconductors. The SSD could learn from its peer NMIs that have been successful in serving a wider range of industries.

The SSD could establish a strategic cross-sector approach for dissemination of technical services and research (e.g., create dedicated channels for targeted sectors), ensuring greater uptake in both traditional and emerging sectors. Additionally, further strengthening collaborative mechanisms with public and private partners could improve cross-sector and cross-technical disciplinary engagement. An example of this is fostering multidisciplinary initiatives, such as establishing annual or biannual stakeholder conferences, workshops, and open house events, including industrial partners and peer NMIs.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion 6-1: The Sensor Science Division benefits from a well-established funding stream of base funding, calibration fees, and external research funding that supports operation of the facilities. Nevertheless, infrastructure maintenance and equipment replacement remain pressing challenges for which there is very limited funding. Financial planning that prioritizes infrastructure upgrades and equipment replacement—especially where cross-industry sector customer impact is likely—is prudent. Facility-related issues (building condition, past flooding concerns) and equipment issues (outdated instrumentation with increased risk of malfunction) persist, impacting capabilities (e.g., efficiency, staff utilization, calibration services, research).

Recommendation 6-1: Aging facilities and outdated equipment constrain productivity and innovation, and pose risks to the continuity of calibration services and research activities within the Sensor Science Division (SSD). The Physical Measurement Laboratory leadership, in collaboration with SSD and National Institute of Standards and Technology leadership and the Office of Facilities and Property Management should consider infrastructure and equipment investments that address these constraints. The SSD could consider a Layer Process Assessment focused on technology readiness, efficiency gains, and the potential to incorporate more automation. This would improve operational reliability, service delivery, research output, and the division’s ability to sustain and expand its impact through partnerships.

Conclusion 6-2: The current operational finance model of the Sensor Science Division (SSD) could be improved to better serve a broader range of economic sectors. The division's financial planning is strongly influenced by defense industry-focused needs, which can limit opportunities to leverage broader outside investment and private-sector partnerships. The funding models of peer National Metrology Institutes may serve as a reference for integrating broader economic sectors. Utilizing experts in strategic planning and marketing would help the SSD align laboratory capability and capacity with future-facing opportunities.

Recommendation 6-2: The current focus on advancing metrology and calibrations for defense and semiconductor sectors limits broader innovation in measurement science for the needs of other sectors in the U.S. economy. The Sensor Science Division should develop a strategic plan to diversify its research into sectors such as advanced manufacturing and agricultural sensing to enhance resilience, impact, and relevance. This should utilize an external facilitator and multisector advisory panel and include outreach to potential university and industry partners to develop new business opportunities and partnerships.

Conclusion 6-3: The Sensor Science Division has a strong collaborative leadership team, which supports cross-dependence among different groups within the division.

Conclusion 6-4: The Sensor Science Division's (SSD's) current research expertise is focused on specific sectors (e.g., defense, semiconductor), limiting adaptability to fast-evolving priorities in sectors such as advanced manufacturing and agricultural sensing. Developing sustained partnerships with universities, commercial laboratories, or consortia would improve talent recruitment and could allow the SSD to leverage external partnerships to complement its resources, improving both technical capability and capacity.

Conclusion 6-5: While the Sensor Science Division (SSD) boasts world-class technical capabilities and a highly skilled team, more than 40 percent of the staff are at or above retirement age. Strategic hiring, mentoring, and cross-disciplinary skill development are essential to sustain long-term success and meet growing stakeholder demands. The

PREPUBLICATION COPY—Uncorrected Proofs

emerging professionals program at the SSD is best in class, indicating an appropriate consideration of the beginning of the career pipeline.

Recommendation 6-3: The Sensor Science Division should continue to focus on its emerging professionals program to ensure that it has appropriate staffing levels and expertise to remain an industry leader. It should enhance strategic mentoring and development of cross-domain expertise to help ensure future-ready research programs.

Conclusion 6-6: The Sensor Science Division has developed metrics that quantify its impact to its stakeholders and industry sectors. Continued outreach and engagement with its stakeholders and industry peers is necessary to remain best in class. This may include new metrics and regular engagement events such as annual workshops that will amplify its influence and ensure continued alignment with stakeholder needs.

Recommendation 6-4: The Sensor Science Division (SSD) should strengthen its outreach and stakeholder engagement in alignment with its strategic plan, drawing on comparative insights from peer National Metrology Institutes to identify effective practices in funding approaches, service pricing models, success metrics, and industry engagement. In addition, the SSD should increase its emphasis on collaborative, cross-sector research activities, including participation in international standards development, to better identify emerging needs across a broader range of sectors and to expand its customer base and overall impact.

REFERENCE

PML (Physical Measurement Laboratory). 2025. Read-Ahead Material for NASEM Assessment of PML. National Institute of Standards and Technology, Gaithersburg, MD. Including updated actual obligated budget figures from Maria Nadal, National Institute of Standards and Technology, March 25, 2026.

7

Conclusions and Recommendations

The panel’s conclusions and recommendations include overarching conclusions and key recommendations described in the Summary and the conclusions and recommendations specific to each division, which appear in Chapters 2–6.

OVERARCHING CONCLUSIONS AND KEY RECOMMENDATIONS

This report addresses the critical core mission of the National Institute of Standards and Technology (NIST) in improving the precision and furthering the dissemination of the International System of Units (SI), carrying out crucial calibrations of measurement instruments and devices used across the nation in industrial and government sectors, and in advancing measurement science generally. The panel observed outstanding work being accomplished by dedicated staff across all NIST Physical Measurement Laboratory (PML) divisions being reviewed.

The successful fulfillment of this mission is threatened by three critical issues: (1) lack of adequate staffing, especially at the senior level in many areas across all PML divisions; (2) severe laboratory infrastructure failures, affecting health and safety of personnel, ability to perform timely calibration for external customers, and threatening damage to valuable equipment; and (3) old, outdated instrumentation affecting the precision and reliability of measurements and calibrations. All three issues are caused or exacerbated by lack of sufficient funding.

The critical lack of staffing is due to a variety of issues: senior staff retirements, decisions to take government-wide departure offers, and more remunerative opportunities in the academic and private sectors. At the same time, some of the training programs for early-career scientists, such as the National Research Council postdoctoral appointments, were paused in early and mid-2025 and then restarted—suspending the important pipeline of junior staff in measurement

science. The loss of staff has resulted in single-point failures in which an individual trained to carry out certain measurements or calibrations has left abruptly or is at risk of leaving, with no one yet trained to take over their role. Timely response to calibration requests is thus affected. In some cases, at the time of review, retirements of senior staff and hiring freezes resulted in vacancies at the leadership level in the divisions, sometimes filled in an acting capacity.

In some divisions, laboratory work is being carried out in rooms that experience periodic flooding, in some cases giving rise to uneven floors, which create serious safety issues. Lack of attention to adequate laboratory infrastructure, such as enough available electrical outlets, necessitates long extension cords—another safety hazard. Inability to control laboratory conditions such as temperature and humidity negatively impacts timely calibrations and high-precision scientific experiments. These problems have been pointed out in several previous assessment reports (NASEM 2016, 2021), and yet they persist. Old and outdated instrumentation, some more than 30 years old, affects the accuracy and reliability of measurement science and calibrations in two of the divisions.

These observations prompt four overarching conclusions and three key recommendations:

Overarching Conclusion 7-1: The National Institute of Standards and Technology Physical Measurement Laboratory performs outstanding work accomplished by dedicated staff across all divisions being reviewed.

Overarching Conclusion 7-2: Staffing shortages have arisen at the National Institute of Standards and Technology (NIST) Physical Measurement Laboratory (PML) from long-standing issues (retirements of senior staff, better compensation elsewhere) and newer problems (government-wide incentivized departures). Staffing shortages are especially critical at an institution like PML, where staffing is already tight and certain critical services are only performed by single individuals. This leads to single-point failures to provide in a timely fashion aspects of the NIST core mission in calibration, dissemination of the International System of Units, measurement science, innovation, and industrial competitiveness.

Overarching Conclusion 7-3: Some laboratory conditions at the National Institute of Standards and Technology (NIST) Physical Measurement Laboratory are unsafe due to flooding and insufficient electrical supply. Poor environmental controls also lead to failures to provide aspects of the NIST core missions in calibration, standards, measurement science, innovation, and industrial competitiveness.

Overarching Conclusion 7-4: Outdated instrumentation is a potential single point of failure, and was identified as a major issue in two National Institute of Standards and Technology Physical Measurement Laboratory divisions (Radiation Physics and Sensor Science). Antiquated devices have decreased measurement accuracy and precision, and when they fail, work is delayed during repair or replacement.

Key Recommendation 7-1: The leadership of the National Institute of Standards and Technology Physical Measurement Laboratory should address critical staffing at all levels and ensure that training of more junior staff is adequate to avoid single-point failures.

Key Recommendation 7-2: National Institute of Standards and Technology (NIST) Physical Measurement Laboratory leadership, in coordination with NIST leadership and the Office of Facilities and Property Management, should begin a schedule of repair or replacement of laboratories that are subpar to eliminate hazardous safety conditions and serious hindrances to scientific work.

Key Recommendation 7-3: The leadership of the National Institute of Standards and Technology Physical Measurement Laboratory (PML) should assess equipment across the divisions, with a focus on equipment that can create single points of failure, or which limit the accuracy or precision of calibration services. PML should then reprioritize funding to replace or upgrade problematic equipment identified in its review.

DIVISION-SPECIFIC CONCLUSIONS AND RECOMMENDATIONS

Microsystems and Nanotechnology

Conclusion 2-1: The research within the Microsystems and Nanotechnology Division is world leading, and the division continues to define new, emerging technologies.

Examples include defining a new unit for radiation exposure and achieving new standards and record precision in acceleration measurement. However, the research approach sometimes appears reactionary to immediate stakeholder needs rather than forward looking and strategic, and could benefit from earlier engagement with stakeholders to help the division maintain its premier strength and leadership.

Recommendation 2-1: The leadership of the National Institute of Standards and Technology Physical Measurement Laboratory (PML) should encourage group leaders to participate in leadership opportunities within their respective research communities. Staff and associates should be encouraged to attend major conferences and stakeholder working groups to connect with external communities frequently. Microsystems and Nanotechnology Division leadership should engage earlier with semiconductor industry and metrology tool vendors to help define new research directions and metrology and measurement innovation goals, and to improve long-term strategy roadmaps at the group level.

Conclusion 2-2: The nanofabrication facility is world class and has acquired new, state-of-the-art instrumentation because of the Creating Helpful Incentives to Produce Semiconductors and Science Act. The Microsystems and Nanotechnology Division's integration team is critical for facilitating fabrication efforts throughout the National Institute of Standards and Technology and for other stakeholders. However, the current staff are overstretched in managing the expanding facility, and research capabilities have suffered, and will continue to suffer, because of staff attrition and anticipated retirements.

Recommendation 2-2: The leadership of the Physical Measurement Laboratory should prioritize support for the nanofabrication facility, including providing specific, dedicated funds to hire junior staff, whom senior staff can mentor and train to set up new tools, support existing tools, and respond to the needs of expanded programs.

Conclusion 2-3: The Microsystems and Nanotechnology Division employs many postdoctoral fellows and early-career staff who are very satisfied with their individual research. However, postdoctoral fellows have expressed a desire for clearer guidance regarding steps that are needed to advance their career.

Recommendation 2-3: The leadership of the National Institute of Standards and Technology (NIST) and the Physical Measurement Laboratory (PML) should evaluate their hiring practices, mentoring and professional development programs, and community-building efforts for postdoctoral researchers to improve their experience at NIST. Specifically, NIST leadership should work with universities in the Professional Research Experience Program to minimize hiring delays and, to the extent possible, secure annual cost-of-living adjustments for postdoctoral researchers. PML leadership should establish a mentoring program to advise postdoctoral researchers on their NIST career, with clear guidance on the pathway from early-career associate to federal employee. To help foster a sense of community, NIST leadership should take concrete steps to enable researchers to connect with each other, such as reopening shared spaces like the cafeteria.

Conclusion 2-4: The stakeholder testimonials suggest that the Microsystems and Nanotechnology Division has positive, beneficial interactions with industry, but they are specific, limited examples. It would be useful to add additional laboratory-wide metrics to evaluate the long-term impact of programs.

Recommendation 2-4: The leadership of the National Institute of Standards and Technology (NIST) Physical Measurement Laboratory (PML) should consider tracking additional metrics to review dissemination and demonstrate impact. For example, PML could evaluate the career path of associates trained through NIST

PREPUBLICATION COPY—Uncorrected Proofs

programs, or track product lines developed, instruments impacted, financial impacts on industry sector sizes, or staff members trained. These metrics could be collected through stakeholder surveys and could help demonstrate the long-term value and impact of PML.

Radiation Physics

Conclusion 3-1: The Radiation Physics Division (RPD) of the National Institute of Standards and Technology's Physical Measurement Laboratory operates with varying levels of aging infrastructure. Specifically, there are underground laboratory and corridor areas that sustained substantial water damage, and flooding can happen on a regular basis in the RPD building. There is evidence of flooding that significantly warped the flooring around a radioactive source. This flooring introduced tripping hazards and lacked structural integrity. Moreover, inadequate electrical infrastructure resulted in excessive use of extension cords. These issues not only pose several serious safety concerns but also hinder the staff's ability to do their work and conduct scientific measurements.

Recommendation 3-1: The leadership of the National Institute of Standards and Technology (NIST) Physical Measurement Laboratory should conduct a safety review of all Radiation Physics Division (RPD) laboratories and in collaboration with RPD and NIST leadership and the Office of Facilities and Property Management should establish a plan for flood and water damage mitigation and laboratory safety integrity.

Conclusion 3-2: National Institute of Standards and Technology (NIST) calibration services supplied to external stakeholders (e.g., Accredited Calibration Laboratories) are critical to the nuclear industry. There appear to be multiple occurrences where a single point of failure, due to either failing equipment or insufficient staff, in the Radiation Physics Calibration Program could potentially cause catastrophic delays to its external customers, who are required under Title 10 of the Code of Federal Regulations (10 CFR) Part 20 and 10 CFR Part 35 to use NIST-traceable radiation detectors.

PREPUBLICATION COPY—Uncorrected Proofs

Recommendation 3-2: The leadership of the National Institute of Standards and Technology Physical Measurement Laboratory and the Radiation Physics Division (RPD) should identify and stratify all mission-critical “single-point failures” in the RPD and implement remedies to those items. At a minimum, at least two people should be trained to perform all instrument calibration work, and all radiation calibration-centric electronics used by the RPD should be examined and updated as needed. Additional staff may be required to ensure timely calibrations.

Conclusion 3-3: The current National Institute of Standards and Technology practice of funding only a few large research projects through the Innovations in Measurement Science funding mechanism appears to limit the number of potentially beneficial projects and inhibit the development of new projects.

Recommendation 3-3: The leadership of the National Institute of Standards and Technology Physical Measurement Laboratory should consider a funding mechanism that creates more opportunities to fund smaller innovative projects.

Conclusion 3-4: Internal purchasing processes have reportedly become sufficiently burdensome to counter their intended goal of controlling and reducing costs. Researchers reported that three quotes are needed to purchase an item, no matter how inexpensive that item is. The process of obtaining these quotes often results in a greater person-time cost than the cost of the actual items. Previously, some items were available through a centralized storeroom, which was phased out over the current purchasing process.

Recommendation 3-4: The leadership of the National Institute of Standards and Technology Physical Measurement Laboratory should consider establishing a threshold based on a cost analysis where items below a certain value do not require multiple quotes.

Nanoscale Device Characterization

Conclusion 4-1: The leadership of the Nanoscale Device Characterization Division has done an excellent job balancing the core mission of the National Institute of Standards and Technology while also making progress toward application-driven goals. Most of the projects in the division support multiple Physical Measurement Laboratory goals, such as defining and disseminating the International System of Units, quantum science, and artificial intelligence.

Conclusion 4-2: The Nanoscale Device Characterization Division has improved its collaboration with industry, as recommended in the previous National Academies report. Collaboration with industry has enhanced both the scientific and application-oriented research in the division. Industrial collaboration has also enhanced the public impact of the division through both commercial applications and the development of trusted standards.

Conclusion 4-3: The scientific output of the Nanoscale Device Characterization Division is world class. This record of publications and talks is essential for recruiting and retaining exceptional talent in the division.

Recommendation 4-1: The leadership of the National Institute of Standards and Technology Physical Measurement Laboratory and the Nanoscale Device Characterization Division (NDCD) should ensure that NDCD scientists are able to disseminate their results and communicate with their research communities in government, academia, and industry robustly, particularly through conference and workshop travel and follow-up conversations with the identified experts.

Recommendation 4-2: The Physical Measurement Laboratory leadership in collaboration with the Nanoscale Device Characterization Division and National Institutes of Standards and Technology leadership and the Office of Facilities and Property Management should prioritize maintenance and operations actions that ensure that the facilities and infrastructure problems do not endanger the core scientific mission.

PREPUBLICATION COPY—Uncorrected Proofs

Quantum Measurement

Conclusion 5-1: The Quantum Measurement Division demonstrates world-class calibration and research capabilities. It is critical to the core National Institute of Standards and Technology (NIST) mission of realizing and disseminating the International System of Units (mass, force, ampere), which underpins nearly every commercial product in the United States. The teams actively engage with international counterpart National Metrology Institutes to seek consensus and improve NIST's state-of-the-art calibration systems, while working with partners to adapt these systems for wider adoption. While the equipment is adequate for the organization's missions, persistent facility issues, such as problems with processed chilled water and electromagnetic interference, often lead to measurement inaccuracies.

Recommendation 5-1: The National Institute of Standards and Technology (NIST) Physical Measurement Laboratory should collaborate with the Quantum Measurement Division and NIST leadership, and the Office of Facilities and Property Management to continue to pursue facilities upgrades from deferred maintenance (e.g., flood prevention, better humidity control), as the ongoing facility issues drastically impact calibration turnaround times and equipment uptime. The Quantum Measurement Division should consider expanding its use of dedicated technical staff (currently a single engineer who interfaces with the NIST facilities group) to maintain its specialized facilities needed for calibration of equipment and groundbreaking research.

Conclusion 5-2: Quantum Measurement Division staff provide critical voices for defining the country's national quantum initiative strategy and continually generate excellent research in the field of quantum simulation, quantum thermodynamics, and single-photon sources. As the quantum science and technology ecosystem grows, clarifying the National Institute of Standards and Technology's role in the next 5 years will become more important.

Recommendation 5-2: The Quantum Measurement Division (QMD) leadership should create a communication plan with clear industry-relevant metrics that shows

PREPUBLICATION COPY—Uncorrected Proofs

how its research and calibrations have positively impacted U.S. commerce. Such a proactive initiative should spearhead further engagement with industry to identify emerging needs in standards and metrology and enable collaborative updates to existing databases and reports. The leadership of the Physical Measurement Laboratory and the QMD should ensure that valuable databases, such as the one assembled and maintained by the former Atomic Spectroscopy Group, are retained and remain available to government and industrial entities.

Conclusion 5-3: The Quantum Measurement Division (QMD) exhibits high engagement with academic collaborators, especially with the University of Maryland through the Joint Quantum Institute. High-profile publications, especially in metrology, show the continued relevance and quality of the research. In 2025, the QMD lost significant senior staff, both through incentivized early retirement and through transfer to other parts of government. The combination of the Physical Measurement Laboratory's succession planning fund, reinstatement of the National Research Council postdoctoral program, and its plan to backfill currently open positions is critical for maintaining the current level of success at producing scientific achievements needed to enable the precision calibration services the National Institute of Standards and Technology provides that underlie the U.S. economy.

Recommendation 5-3: The Quantum Measurement Division (QMD) should collaborate with other Physical Measurement Laboratory divisions (in both Gaithersburg and Boulder) to formulate a unified strategic approach in quantum technologies (communication, sensing, and computation) and identify a select set of distinctive capabilities that leverage their unique metrology expertise. The QMD should prioritize activities both within and beyond its current expertise, identifying underrepresented areas and organizational weaknesses in critical national technologies, and articulating pathways to address these gaps, including redistribution of efforts between divisions.

Sensor Science

Conclusion 6-1: The Sensor Science Division benefits from a well-established funding stream of base funding, calibration fees, and external research funding that supports operation of the facilities. Nevertheless, infrastructure maintenance and equipment replacement remain pressing challenges for which there is very limited funding. Financial planning that prioritizes infrastructure upgrades and equipment replacement—especially where cross-industry-sector customer impact is likely—is prudent. Facility-related issues (building condition, past flooding concerns) and equipment (outdated instrumentation with increased risk of malfunction) persist, impacting capabilities (e.g., efficiency, staff utilization, calibration services, research).

Recommendation 6-1: Aging facilities and outdated equipment constrain productivity and innovation, and pose risks to the continuity of calibration services and research activities within the Sensor Science Division (SSD). The Physical Measurement Laboratory leadership, in collaboration with SSD and National Institute of Standards and Technology leadership and the Office of Facilities and Property Management should consider infrastructure and equipment investments that address these constraints. The SSD could consider a Layer Process Assessment focused on technology readiness, efficiency gains, and the potential to incorporate more automation. This would improve operational reliability, service delivery, research output, and the division’s ability to sustain and expand its impact through partnerships.

Conclusion 6-2: The current operational finance model of the Sensor Science Division (SSD) could be improved to better serve a broader range of economic sectors. The division’s financial planning is strongly influenced by defense industry-focused needs, which can limit opportunities to leverage broader outside investment and private-sector partnerships. The funding models of peer National Metrology Institutes may serve as a reference for integrating broader economic sectors. Utilizing experts in strategic planning and marketing would help the SSD align laboratory capability and capacity with future-facing opportunities.

PREPUBLICATION COPY—Uncorrected Proofs

Recommendation 6-2: The current focus on advancing metrology and calibrations for defense and semiconductor sectors limits broader innovation in measurement science for the needs of other sectors in the U.S. economy. The Sensor Science Division should develop a strategic plan to diversify its research into sectors such as advanced manufacturing and agricultural sensing to enhance resilience, impact, and relevance. This should utilize an external facilitator and multisector advisory panel and include outreach to potential university and industry partners to develop new business opportunities and partnerships.

Conclusion 6-3: The Sensor Science Division has a strong collaborative leadership team, which supports cross-dependence among different groups within the division.

Conclusion 6-4: The Sensor Science Division's (SSD's) current research expertise is focused on specific sectors (e.g., defense, semiconductor), limiting adaptability to fast-evolving priorities in sectors such as advanced manufacturing and agricultural sensing. Developing sustained partnerships with universities, commercial laboratories, or consortia would improve talent recruitment and could allow the SSD to leverage external partnerships to complement its resources, improving both technical capability and capacity.

Conclusion 6-5: While the Sensor Science Division (SSD) boasts world-class technical capabilities and a highly skilled team, more than 40 percent of the staff are at or above retirement age. Strategic hiring, mentoring, and cross-disciplinary skill development are essential to sustain long-term success and meet growing stakeholder demands. The emerging professionals program at the SSD is best in class, indicating an appropriate consideration of the beginning of the career pipeline.

Recommendation 6-3: The Sensor Science Division should continue to focus on its emerging professional program to ensure that it has appropriate staffing levels and expertise to remain an industry leader. It should enhance strategic mentoring and development of cross-domain expertise to help ensure future-ready research programs.

Conclusion 6-6: The Sensor Science Division has developed metrics that quantify its impact to its stakeholders and industry sectors. Continued outreach and engagement with its stakeholders and industry peers is necessary to remain best in class. This may include new metrics and regular engagement events such as annual workshops that will amplify its influence and ensure continued alignment with stakeholder needs.

Recommendation 6-4: The Sensor Science Division (SSD) should strengthen its outreach and stakeholder engagement in alignment with its strategic plan, drawing on comparative insights from peer National Metrology Institutes to identify effective practices in funding approaches, service pricing models, success metrics, and industry engagement. In addition, the SSD should increase its emphasis on collaborative, cross-sector research activities, including participation in international standards development, to better identify emerging needs across a broader range of sectors and to expand its customer base and overall impact.

REFERENCES

- NASEM (National Academies of Sciences, Engineering, and Medicine). 2021. *An Assessment of Selected Divisions of the Physical Measurement Laboratory at the National Institute of Standards and Technology: Fiscal Year 2021*. Washington, DC: National Academies Press.
<https://doi.org/10.17226/26312>.
- NASEM. 2016. *An Assessment of the National Institute of Standards and Technology Physical Measurement Laboratory: Fiscal Year 2015*. Washington, DC: National Academies Press.
<https://doi.org/10.17226/23448>.

Appendix A

Biographical Sketches of Panel

KATE P. KIRBY (*Chair*) was the chief executive officer at the American Physical Society (APS; 2015–2020). Dr. Kirby earned her bachelor’s degree in chemistry and physics from Harvard/Radcliffe College and her PhD from the University of Chicago. After a postdoctoral fellowship at the Harvard College Observatory, she was appointed as a research physicist at the Smithsonian Astrophysical Observatory and lecturer in the Harvard University Department of Astronomy. From 1988 to 2001, she served as an associate director at the Harvard-Smithsonian Center for Astrophysics, heading the Atomic and Molecular Physics Division. From 2001 to 2007, she served as the director of the National Science Foundation–funded Institute for Theoretical Atomic, Molecular and Optical Physics at Harvard-Smithsonian. From 2009 to 2014, she served as executive officer of APS, before being appointed its first chief executive officer in 2015. Upon her retirement from APS at the end of 2020, she was given the honorary title of chief executive officer, emerita. Dr. Kirby’s research interests lie in the area of theoretical atomic and molecular physics, particularly focusing on the calculation of atomic and molecular processes important in astrophysics and atmospheric physics. She is a fellow of APS and a fellow of the American Association for the Advancement of Science. Before becoming APS executive officer, Dr. Kirby served on the Society’s Executive Board and Council (2003–2006) and chaired the APS Division of Atomic, Molecular, and Optical Physics (1997). Other activities include service on the Department of Energy Basic Energy Sciences Advisory Committee (BESAC; 2003–2010) and co-chair of the BESAC Subcommittee on Theory and Computation, member of the National Academy of Sciences/National Research Council Decadal Assessment Committee for Atomic, Molecular and Optical Science, and member of the Editorial Board of Reports on Progress in Physics (2007–2009).

BALAKUMAR BALACHANDRAN is a distinguished university professor and a Minta Martin Professor at the University of Maryland, College Park, where he has been since 1993. He has

served as the chair of the Department of Mechanical Engineering at the University of Maryland and serves as the director of the Vibrations Laboratory, Dynamics and Control Laboratory, and Computational Dynamics Laboratory in Mechanical Engineering. His research interests include applied physics, applied mechanics, applied mathematics, nonlinear phenomena, dynamics and vibrations, and control. The publications that he has authored or co-authored include a Wiley textbook titled *Applied Nonlinear Dynamics: Analytical, Computational, and Experimental Methods* (1995, 2004), a Thomson/Cengage textbook (2004, 2009), and a Cambridge University Press textbook (2018) titled *Vibrations*. He holds four U.S. patents: three related to fiber optic sensors and one related to atomic force microscopy. He has served as the editor of the American Society of Mechanical Engineers (ASME) *Journal of Computational and Nonlinear Dynamics*, a contributing editor of the *International Journal of Non-Linear Mechanics*, and a deputy editor of the AIAA Journal. He is an ASME fellow, an American Institute of Aeronautics and Astronautics (AIAA) fellow, an honorary fellow of the Royal Aeronautical Society, an ASA full member, and an Institute of Electrical and Electronics Engineers senior member. The different honors he has received include the ASME Melville Medal, Den Hartog Award, Lyapunov Award, and the Thomas Caughey Dynamics Medal, the ASCE Engineering Mechanics Institute Robert Scanlan Medal, and the AIAA Pendray Aerospace Literature Award. Dr. Balachandran received his BTech (naval architecture) from the Indian Institute of Technology, Madras, India, and MS (aerospace engineering) and PhD (engineering mechanics) from Virginia Tech.

CARL BLOOMFIELD is the vice president of quality and accreditations at Intertek. Mr. Bloomfield is in his 29th year at Intertek and during that time has held various engineering and managerial positions. In his current role, he is responsible for the quality and accreditations of Intertek's more than 60 electrical laboratories around the world. He represents Intertek on various technical committees such as Illuminating Engineering Societies Testing Procedures, American National Standard Institute–American National Standard Lighting Group, American Lighting Association, Zhaga Consortium, Commercial Lighting Products–Integrated Committee on Lighting Products, and Underwriters Laboratories Standards and Engagement lighting technical committees. Mr. Bloomfield received his BS in electrical engineering from the University of Florida in 1996.

PREPUBLICATION COPY—Uncorrected Proofs

GEORGE BURBA is a LI-COR Science & Strategy fellow, global fellow at the Daugherty Water for Food Global Institute, graduate adjunct professor at the University of Nebraska, and co-founder and principal of CarbonDew Community of Practice. He has held leadership and advisory roles across numerous scientific, academic, and industry organizations, developing practical technologies that support agriculture, land management, and environmental stewardship, focusing on improving agricultural and energy efficiency, preserving air and water quality, and enhancing food and energy security. Dr. Burba is recognized for his expertise in bio-atmospheric sciences, environmental measurement technologies, and energy and gas flux research, with 14 patents in the United States and more than 40 other countries on successfully commercialized technology, devices, and methods used by government agencies, universities, and private industry worldwide. His innovations contribute to cost-effective monitoring and management of natural resources, supporting regulatory compliance and voluntary stewardship efforts. He is the author of 11 books on the curricula at more than 80 universities and in libraries across the world, and more than 450 scientific, technical, and conference publications cited in the *Proceedings of the National Academy of Sciences*, *Nature*, *Science*, *Environmental Science & Technology*, *Biological Reviews*, *Environmental Research Letters*, *Reviews of Geophysics*, *Energy & Environmental Science*, and more. Dr. Burba has taught and lectured in more than 500 courses, seminars, webinars, and invited lectures, including those at numerous universities, American Flux Network (AmeriFlux), Argonne National Laboratory, Asian Flux Network, Barrow Arctic Science Consortium, Battelle Memorial Institute, the Environmental Protection Agency, Integrated Carbon Observation System (ICOS), Integrated non-CO₂ Greenhouse Gas Observing System (InGOS), Indian Institute of Tropical Meteorology, National Ecological Observatory Network, Australian and New Zealand Flux Research and Monitoring Network, World Meteorological Organization (WMO), X The Moonshot Factory, and served on advisory boards, review panels, steering, grant, search, and organizing committees at more than 40 organizations and groups including AmeriFlux, the Arctic Foundation, CarbonSpace, European Cooperation in Science and Technology, the Department of Energy, Daugherty Water for Food Global Institute, Elsevier, the EU Commission, ICOS, InGOS, National Council for Science and the Environment, NEON, Foundation for Food & Agriculture Research, Israel Ministry of Science, Netherlands Organization for Scientific Research, WMO, and more.

PREPUBLICATION COPY—Uncorrected Proofs

YOUNG-KAI CHEN (NAE) was appointed the deputy chief technology officer (DCTO) for Coherent in July 2022. In this role, Dr. Chen works closely with the chief technology officer to chart the future technical direction of the company, including the creation of new materials for energy generation, transmission, and storage; basic research around next-generation quantum technologies; breakthroughs required for the sixth generation of wireless networks; and the adoption of digital technologies, machine learning, and artificial intelligence across Coherent's operations and in its products and services. Prior to being named DCTO, Dr. Chen was the chief scientist in the company's Wide-Bandgap Electronics Technologies group. Before joining Coherent in 2021, he was a program manager at the Defense Advanced Research Projects Agency, where he initiated and managed programs in advanced semiconductor electronics, secured communications, and artificial intelligence and machine learning processing. Dr. Chen was previously a senior director at Nokia Bell Labs, responsible for advanced research and technology development in high-speed electronics and optoelectronics, including integrated lasers, silicon photonics, coherent optical data links, and wireless backhaul transceivers. Dr. Chen received his PhD from Cornell University in electrical engineering. He is a fellow of Bell Labs, the Institute of Electrical and Electronics Engineers (IEEE), and Optica (Optical Society of America); a member of the National Academy of Engineering; and recipient of the prestigious IEEE David Sarnoff Award and the Edison Patent Award. He has authored or co-authored 3 book chapters and more than 190 journal articles, and he holds 33 U.S. patents.

SHANYING CUI is a senior manager of photonics integration at PsiQuantum, where she leads photonics efforts toward the first fault-tolerant photonic quantum computer. Previously, she was the department manager and principal research scientist at HRL Laboratories, managing the Device Technologies department with programs spanning photonic integrated circuits, III-V infrared detectors, RF GaN transistors, and SiGe spin qubits. She has proposed and led multi-institutional projects on satellite-based quantum repeaters, scalable photonic platforms, and advanced nanomaterials. Dr. Cui serves on technical planning committees for Optica, the Institute of Electrical and Electronics Engineers, the Society of Photo-Optical Instrumentation Engineers (SPIE), and the Quantum Economic Development Consortium. She was appointed to the Defense Advanced Research Projects Agency Microsystems Exploratory Council, a study group that conducts pathfinding studies for the Microsystems Technology Office. Dr. Cui

PREPUBLICATION COPY—Uncorrected Proofs

received her PhD in applied physics from Harvard University and a BS in chemistry from the Massachusetts Institute of Technology.

NATHALIE DE LEON is an associate professor of electrical and computer engineering at Princeton, where she focuses on quantum sensing with nitrogen-vacancy centers in diamond, quantum networks with solid-state defect systems and nanophotonics, and new material platforms for superconducting qubits. She is also an affiliated faculty member in the Physics Department and at the Princeton Plasma Physics Laboratory. She received her BS from Stanford University in 2004 and PhD from Harvard University in 2011. She then worked as a Center for Integrated Quantum Materials (CIQM) and Element Six postdoctoral fellow at Harvard. Dr. de Leon joined the faculty of Princeton University as an assistant professor in electrical and computer engineering in 2016, where she was later promoted to associate professor. Her group works at the interface of quantum optics, atomic physics, condensed-matter and device physics, materials science, surface spectroscopy, nanofabrication, and spin physics to uncover sources of noise and loss in quantum systems and uses these insights to design new quantum platforms. She is currently the materials thrust leader of the Co-design Center for Quantum Advantage, a Department of Energy (DOE) National Quantum Information Science Center, the chair-elect of the American Physical Society (APS) Division of Quantum Information, and the co-director of the Princeton Quantum Initiative. Dr. de Leon received the Air Force Office for Scientific Research Young Investigator Award in 2016, the Sloan Research Fellowship in Physics in 2017, the National Science CAREER Award in 2018, the Defense Advanced Research Projects Agency Young Faculty Award in 2018, the DOE Early Career Award in 2018, the Gordon and Betty Moore Foundation Experimental Physics Investigator Award in 2023, and the APS Rolf Landauer and Charles H. Bennett Award in Quantum Computing in 2023.

BENJ FITZRYSLER presently holds the role of technical manager at Minnesota Weights and Measures, focusing on mass and volume calibrations. He approaches measurement science via analysis of calibration processes and development of uncertainty budgets that incorporate the relevant physics, and uses both of these areas to systematically ameliorate the largest challenges; these improvements range from reducing the largest uncertainty components of the measurements to simplifying measurement and data analysis operations. In particular, he devotes

PREPUBLICATION COPY—Uncorrected Proofs

much of his expertise to elucidating intricacies with the highest level mass calibrations, such as those utilizing automated mass comparators and weighing designs. He is a member of the National Conference of Standards Laboratories International and American Society for Testing and Materials International (ASTM) and is currently participating in the authorship team updating the E617 standard for mass metrology. Dr. FitzRysler received his BS with majors in chemistry, chemical engineering, and mathematics from the University of Wyoming and his PhD in physical chemistry from the University of Chicago in 2010. He completed a postdoctoral fellowship at the University of Minnesota in 2014 and continues his love of science through both his work and his hobbies, such as maintaining a small Linux cluster for computational quantum mechanics calculations.

THOMAS FOLLAND is an assistant professor in the Department of Physics and Astronomy at the University of Iowa. He is an expert in photonics, optoelectronics, metamaterials, and infrared optical spectroscopies. During his graduate and postdoctoral work, he demonstrated the first graphene-controlled terahertz quantum cascade laser and the capability to manipulate hyperbolic polaritons using phase change materials. In his research group at Iowa, he has shown the existence of shear polaritons in low-symmetry materials and developed cryogenic infrared spectroscopy techniques for materials characterization. He was recently awarded a National Science Foundation CAREER award to study the optical properties of low-symmetry materials and is part of an Office of Naval Research Multidisciplinary University Research Initiatives team on twist optics. He is a member of the Materials Research Society and is an active member of the early-career subcommittee. Professor Folland received his MPhys in physics in 2012 and a PhD in nanoscience in 2017 from the University of Manchester, United Kingdom. Professor Folland published one article, “Experimental confirmation of long hyperbolic polariton lifetimes in monoisotopic (^{10}B) hexagonal boron nitride at room temperature,” with National Institute of Standards and Technology staff scientist Andrea Centrone.

NATHAN GEMELKE is a co-founder of QuEra Computing, its chief technology strategist, and an expert in experimental atomic physics and quantum simulation and computation with neutral atoms. Prior to joining QuEra full time, he held a research faculty appointment at Penn State University and obtained his PhD from Stanford University under former Energy Secretary

PREPUBLICATION COPY—Uncorrected Proofs

Steven Chu. Dr. Gemelke has more than 20 years of experience conducting and leading academic research. His work centers on the use of laser-cooled atomic gases to study quantum computation and information sciences, organizational principles of many-body physics in the quantum limit, and novel effects in quantum and nonequilibrium statistics. As a voice of industry in quantum technologies, he frequently consults on national strategy in quantum information sciences for national and local governments and their agencies.

IGOR GOLOVKIN is a chief technology officer at Prism Computational Sciences—a company that develops and applies innovative software tools for scientific research and commercial applications in the physical sciences and engineering. His main focus of research has been on the study of plasmas created in high-power laser, z-pinch, and ion beam experiments performed at major national laboratories and universities. He leads the development of radiation-hydrodynamics and synthetic diagnostics simulation tools applicable to research in high-energy-density laboratory plasmas. Dr. Golovkin received his MS in mathematical physics from Moscow State University in 1993 and PhD in atomic and plasma physics from the University of Nevada, Reno, in 2000. Related interests include high-performance computing, metaheuristics, and magnetic and inertial fusion.

GUOHAN HU is currently a distinguished research scientist at the IBM T.J. Watson Research Center and the program lead of the IBM-Samsung Magneto-resistive Random-Access Memory (MRAM) Alliance. Dr. Hu has more than 20 years of experience in the field of spintronics and has led the MRAM materials and device research activities at IBM for the past 12 years. Her work on spin-transfer torque (STT) MRAM has played a significant role in the commercialization of STT-MRAM and was recognized with the 2025 Institute of Electrical and Electronics Engineers (IEEE) Cleo-Brunetti Award. Dr. Hu is a fellow of the IEEE and the American Physical Society. She is also the recipient of the 2024 Mid-Career Award from the IEEE Magnetics Society. Dr. Hu received her BE in materials science and engineering from Tsinghua University in China and PhD in materials science and engineering from Cornell University in 2002.

JUN JIAO is a professor in the Department of Mechanical and Materials Engineering at the Maseeh College of Engineering and Computer Science, Portland State University (PSU). She was the founding director of PSU's Center for Electron Microscopy and Nanofabrication, where she served for 18 years (2003–2021). Under her leadership, the center acquired state-of-the-art research instrumentation, including transmission electron microscopy, scanning electron microscopy, focused ion beam, and physical vapor deposition systems, and more. Dr. Jiao teaches core courses in electron microscopy and spectroscopy techniques for materials and device characterization. Her principal research interests focus on the synthesis and fabrication of nanoscale materials and devices for technological applications. Her work includes the property-controlled growth of graphene and its hybrids with metals and metal oxides for spintronic and nanoelectronic devices, as well as the development of fabrication techniques to hybridize nanocrystals with industrial catalysts for groundwater treatment. Her research has resulted in more than 280 publications and 5 issued patents. Dr. Jiao has been invited to deliver keynote speeches at numerous national and international conferences and workshops. In May 2003, she was invited to testify before the U.S. Senate Committee on Commerce, Science, and Transportation in Washington, DC, on the 21st Century Nanotechnology Research and Development Act. In recognition of her outstanding early-career achievements, Dr. Jiao received the 2004 Presidential Early Career Award for Scientists and Engineers, the highest honor bestowed by the U.S. government on scientists and engineers beginning their independent research careers. In June 2024, she was inducted as a senior fellow of the National Academy of Inventors.

FRANK LIEBMANN graduated from the University of Utah with a BS in electrical engineering. He is currently a metrology engineer for the Fluke Calibration American Fork Laboratory. He is also the National Conference of Standards Laboratories International vice president over the Western Division. He has worked at the American Fork location since 2003. Since 2005, he has worked on establishing and maintaining radiation thermometry metrology at Fluke. This work has included the establishment of a series of blackbody sources and flat-plate infrared calibrators and National Voluntary Laboratory Accreditation Program accreditation for two different radiometric calibrations at Fluke in American Fork. Frank is an American Society for Testing and Materials International (ASTM) fellow. He is currently serving as chair for the

PREPUBLICATION COPY—Uncorrected Proofs

ASTM E20.02 Subcommittee on Radiation Thermometry. He is also a member of the American Meteorological Society and the American Radio Relay League. He has published a number of papers on both contact and noncontact thermometry.

CHRISTOPHER MARTEL is currently the senior director of operations for Radiation Safety and Control Services, Inc. Prior to his current role, Dr. Martel has served as the director of health physics for Brigham and Women's Hospital, and similarly for Boston University and Boston Medical Center. He has expertise in internal and external radiation dosimetry in occupational settings as well as for patients in diagnostic settings in radiology and nuclear medicine. Dr. Martel served as the radiation expert on Institutional Review Boards and Radioactive Drug Research committees. He is a fellow of the Health Physics Society. Dr. Martel received his undergraduate and graduate degrees from the University of Massachusetts in Lowell and his PhD from Worcester Polytechnic Institute in nuclear science and engineering. He is a certified health physicist with more than 40 years of experience in several industries. Dr. Martel has held faculty appointments at Harvard Medical School and the Worcester Polytechnic Institute and maintains an appointment as assistant professor in radiology at the Boston University School of Medicine.

DAVID MEDICH is a professor in the Department of Physics at Worcester Polytechnic Institute and serves as the director of their nuclear science and engineering program. His research interests are in the subfields of health physics and medical physics and include neutron biological imaging, next-generation nuclear reactors, intensity-modulated brachytherapy, and particle resuspension kinetics. He has served as a qualified expert for the International Atomic Energy Agency and was a vice chair of the International Organization for Standardization (ISO) Radiation Protection Committee (ISO TC85 SC2). He presently is the chair of the American Board of Health Physics, chair of the American National Standards Institute's Operational and Medical Health Physics Section, N13, and on the Editorial Board of the *Health Physics Journal*. He was elected to be a fellow of the Health Physics Society in 2022.

JOHN NICHOL is an associate professor in the Department of Physics and Astronomy at the University of Rochester. Dr. Nichol investigates the quantum mechanics of nanoscale objects,

PREPUBLICATION COPY—Uncorrected Proofs

especially individual electrons in semiconductor quantum dots. Dr. Nichol's current research focuses on improving the coherence of electron spin qubits using new materials and control methods, exploring new ways to transfer quantum information between distant spin qubits, and many-body quantum coherence in spin chains. Dr. Nichol is the recipient of a National Science Foundation CAREER award, a Google Research Scholar Award, and a Moore Foundation Experimental Physics Investigator Award. He earned a PhD from the University of Illinois Urbana-Champaign and a BA from St. Olaf College.

EDWARD O'BRIEN is currently a distinguished member of the technical staff and the project lead of the Direct Current (DC) Metrology Lab at the Primary Standards Laboratory of Sandia National Laboratories. Prior to this role, Mr. O'Brien was the project lead of the Alternating Current (AC) Metrology Lab for 5 years. In this position, Mr. O'Brien supports measurements throughout Sandia with a focus on primary resistance and voltage, current shunts, pulsed voltage and current, AC-DC difference, impedance, turns ratio, time, and frequency. Mr. O'Brien graduated from the State University of New York Binghamton with his BS and MS in electrical engineering. Mr. O'Brien serves on the Board of Directors for the National Conference of Standards Laboratories International and is on the Executive Committee for the Conference on Precision Electromagnetic Measurements.

RAYMOND BENTON PAHLKA is a diagnostic medical physicist at Texas Children's Hospital in Houston. He has experience in clinical diagnostic and medical nuclear physics, radiation detector design, neutron physics, and low background radiation measurement. He is a member of the American College of Radiology and the American Association of Medical Physicists. Dr. Pahlka received his BS in physics and mathematics from The University of Texas at Austin, MS in health physics from Texas A&M University, MS in radiological protection from the University of Oklahoma Health Sciences Center, and PhD in physics from The University of Texas at Austin. He completed a postdoctoral fellowship at Fermi National Accelerator Laboratory and a fellowship in imaging physics from The University of Texas MD Anderson Cancer Center. He has published research articles across all of these subfields of radiation physics.

PREPUBLICATION COPY—Uncorrected Proofs

DANIEL SCHMIDT is currently a manager and senior engineer at IBM Research in Albany, New York, where he leads a team of engineers driving metrology developments for next-generation semiconductor manufacturing. He is primarily focused on nondestructive dimensional and materials characterization using in-line optical and x-ray techniques. Prior to joining IBM Research, Dr. Schmidt was a senior research fellow at the National University of Singapore and worked at GlobalFoundries leading extreme-ultraviolet (EUV) overlay metrology development as well EUV lithography process characterization. He is a member of the Society of Photo-Optical Instrumentation Engineers (SPIE) and has received several research awards, including the Diana Nyssonen Memorial Best Paper Award. Dr. Schmidt received his undergraduate degree in microsystems technology from the University of Applied Sciences in Kaiserslautern, Germany, and earned a PhD in electrical engineering from the University of Nebraska–Lincoln in 2010. He has authored or co-authored more than 110 conference papers, more than 70 journal articles, more than 20 U.S. patents and applications, and 3 book chapters. Dr. Schmidt is a guest lecturer at Rensselaer Polytechnic Institute and a guest editor for the *Journal of Micro/Nanopatterning, Materials, and Metrology*. He serves as a committee member at the SPIE Advanced Lithography and Patterning Symposium as well as the International Conference on Spectroscopic Ellipsometry and is involved with the Semiconductor Research Corporation working on semiconductor roadmaps.

BRIJ SINGH is an electrification research and development manager at John Deere USA. He has authored or co-authored more than 100 research papers and has been granted 39 U.S. patents. His current research interests include wide-bandgap technologies, power electronics for precision agriculture, vehicles' electrification, electric motor control systems, and power converters. Dr. Singh is a recipient of four teaching awards at Tulane, where he worked as assistant professor of electrical engineering. At John Deere, Dr. Singh won three innovation awards and one collaboration award. In 2020, he was awarded the “Power Electronics Engineering Fellow” title by John Deere. He also won the 2020 Institute of Electrical and Electronics Engineers (IEEE) Power Electronics Emerging Technology Award. Presently, Dr. Singh is serving as the chair of the IEEE Power Electronics Society Distinguished Lecturer program. In June 2023, the Department of Energy recognized Dr. Singh's outstanding contributions and insightful technical expertise with a Distinguished Achievement Award.

PREPUBLICATION COPY—Uncorrected Proofs

LYDIA SOHN is a professor in the Mechanical Engineering Department at the University of California (UC), Berkeley, where she holds the Almy C. Maynard and Agnes Offield Maynard Chair in Mechanical Engineering and is a core member of the University of California, San Francisco–University of California, Berkeley, Graduate Program in Bioengineering. Dr. Sohn’s research is focused on developing microfluidic platforms to investigate susceptibility and resilience of disease and has been awarded several patents on her innovative platform designs. She has received numerous awards, including the National Science Foundation (NSF) CAREER Award and the Army Research Office Young Investigator Award, and is a fellow of the American Institute for Medical and Biological Engineering. Dr. Sohn received her AB in physics and chemistry (1988) from Harvard-Radcliffe Colleges, and an AM in physics (1990) and PhD in physics (1992) from Harvard University. Dr. Sohn was a NSF/North Atlantic Treaty Organization postdoctoral fellow at Delft University of Technology and a postdoctoral fellow at AT&T Bell Laboratories. Dr. Sohn was a standing member of the National Institutes of Health Instrumentation and Systems Development Study Section and chaired or co-chaired a variety of special emphasis panels focused on technology development and applications.

STEVEN STAHLEY began his career at the Department of Defense, U.S. Navy, as a metrologist at the Naval Avionics Center, Indianapolis, Indiana. This role provided an invaluable opportunity to apply his physics background to the science of measurements, working on projects as diverse as the Tomahawk Cruise Missile and the Space Shuttle’s guidance systems. After several years working with the Navy, Stahley moved to a private company, WaveTech/Datron, a UK-based electronic test and measurement company, as the senior metrologist, quality leader, and service manager, leading service centers in Indianapolis, Indiana, and San Diego, California. This role allowed him to hone his leadership skills, deepened his understanding of international business practices, and developed his first comprehensive laboratory quality system. Ultimately in 1993, Stahley started with Cummins, where he would spend 30 years of his career, holding several positions including aftermarket quality leader, supplier quality for sensors, Engine Control Modules, wiring harness and catalysis and moving finally to lead the corporate metrology team. Stahley did leave Cummins in 2000, for a brief stint, and started his own consulting company, SRS Technical Services, where he provided

PREPUBLICATION COPY—Uncorrected Proofs

consulting services in the areas of metrology, quality systems, and laboratory accreditation. Some of his major clients included the U.S. Agency for International Development, where he led a project to evaluate Kyrgyzstan's application to the World Trade Organization and any potential technical barriers to trade. Stahley also worked with the National Testing Services, where he started a laboratory accreditation body. Finally, he rejoined Cummins as the leader of the central measurement services team, which globally supports Cummins plants and technical centers and which includes leadership of the corporate measurement centers in Indiana, China, and India, where he continues as the director of measurement excellence. During Stahley's career he has spent more than 40 years working with several professional trade organizations, including the National Conference of Standards Laboratories International, the National Cooperation of Lab Accreditation, and the Automotive Industry Action Group, serving on the board of directors and/or committees writing national standards.

CHERYL XU is currently a professor in the Department of Mechanical and Aerospace Engineering at North Carolina (NC) State University and a research fellow (on sabbatical) in the Advanced Materials and Manufacturing Technologies Office at the Department of Energy. Dr. Xu is an expert in multifunctional ceramic materials, high-temperature wireless sensing, and artificial intelligence for process modeling and control, with extensive experience leading federally funded research programs for aerospace and energy applications. She has played key roles in developing advanced manufacturing technologies and materials for extreme environments, including turbine engines, nuclear reactors, and other harsh applications. Dr. Xu is a Fellow of the National Academy of Inventors, a Fellow of the American Society of Mechanical Engineers. She also served as a Science & Technology Policy fellow of the American Association for the Advancement. She is a Life Member of the Society of Manufacturing Engineers. She was the founding Editor-in-Chief of *npj Advanced Manufacturing*, a journal in the Nature portfolio. She received her PhD in mechanical engineering from Purdue University in 2006. Dr. Xu was invited by the National Academies of Sciences, Engineering, and Medicine to present her research at "High Temperature Electromagnetic Materials: A Meeting of Experts" held on March 2, 2023, in Washington, DC. She co-chaired the Thermal Management Symposium, held on March 18–19, 2024, at NC State University in collaboration with the

PREPUBLICATION COPY—Uncorrected Proofs

American Carbon Society, bringing experts from government, industry, and academia to explore advancements in high-temperature materials and thermal technologies.

PREPUBLICATION COPY—Uncorrected Proofs

Appendix B

Definitions of Qualitative Descriptors

Throughout this assessment, the panel makes qualitative statements about the National Institute of Standards and Technology (NIST) Physical Measurement Laboratory’s (PML’s) achievements—for example, that PML performs high-quality research and produces high-impact publications in specific fields. Table B-1 provides a list of the qualitative descriptors used in the report and the panel’s definitions of the terms.

TABLE B-1 Definitions of Qualitative Descriptors

Term	Definition Used by the Panel
Cutting-edge	The aspect of NIST PML being described is at the forefront of its field, to the panel’s knowledge
First-of-a-kind	The aspect of NIST PML being described has never been achieved before, to the panel’s knowledge
<u>High-impact</u>	Describing publications or journals, those disseminating groundbreaking research that has been peer reviewed and is highly cited by other researchers
High-quality	Describing research publications, those disseminating results of rigorous experimentation or theory that have been peer reviewed
One-of-a-kind	The aspect of NIST PML is the only example in the world, to the panel’s knowledge
State-of-the-art	The item being described is the most technologically advanced or newest in its field
World-class	The aspect of NIST PML being described is <i>among the best</i> in the world, to the panel’s knowledge
World-leading	The aspect of NIST PML being described is <i>the best</i> in the world, to the panel’s knowledge
World-renowned	The international community recognizes this aspect of NIST PML as leading in the field