Nanotechnology for the Intelligence Community

Committee on Nanotechnology for the Intelligence Community, National Research Council

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Committee on Nanotechnology for the Intelligence Community
National Materials Advisory Board
Division on Engineering and Physical Sciences

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

R. Stephen Berry, University of Chicago,
Aladar A. Csontos, U.S. Nuclear Regulatory Commission,
Robert J. Dowding, U.S. Army Research Laboratory,
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George W. Sutton, ANSER Corporation, and
William M. Tolles, Consultant

The review of this report was overseen by Robert A Frosch, Harvard University. Appointed by the NRC, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. While the individuals listed above provided many constructive comments and suggestions, responsibility for the final content of the report rests entirely with the authoring committee and the institution.

PREFACE

The intelligence community (IC) of the United States faces a different set of challenges from those that dominated its formative years during the Cold War. The collapse of the Soviet Union, the acceleration of globalization, and the emergence of terror as the primary threat to U.S. society are but a few of the salient aspects of this new environment.

Another dimension of change is the revolutionary advance in scientific understanding and its application across many new technologies. An example is nanotechnology and the development of new tools to analyze and manipulate matter at the molecular level. The pace of technology growth and its rate of proliferation across the world also present major new challenges. The opportunities that these advances represent require new and more aggressive ways to extract positive advantage. The ability of terrorists and other threats to access these advances is a growing concern relating to our security.

STATEMENT OF TASK

The IC requested that the National Materials Advisory Board of the National Research Council undertake a study of the rapidly developing area of nanotechnology and its implications for the IC's various missions. Specifically, the statement of task for this work was as follows:

> The National Materials Advisory Board will form a Committee that will conduct a number of activities to illustrate the potential for nanotechnology to address key intelligence community needs. The Committee of experts undertaking this task shall
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> also discuss new and disruptive technologies to address these needs, and assess opportunities to counter these technologies.
>
> The Committee will:
>
> 1. Describe the technology challenges and opportunities for nanotechnology to enable new functions and systems for use by the intelligence community. Consider the implications of miniaturization, science at the nanoscale, and atomistic and molecular assembly in two separate workshops for the following:
>
> a. Power technologies
> b. Sensing and positioning technologies
>
> 2. Evaluate the potential for advances in these technologies to address needs as presented to the Committee by the intelligence community.
>
> 3. For each technology, describe a path and associated risks to achieve near-term (immediate), mid-term (3-5 years), and long-term (10 years) goals. Consider the infrastructure, including equipment, human resources, and knowledge base, needed to carry out these activities.
>
> 4. In addition, discuss potential new and disruptive ways that nanotechnology can address these intelligence community needs.
>
> 5. Assess opportunities to counter these predicted technology capabilities.

STUDY DELIVERABLES

In response to Task 1 above, the Committee held a workshop on power technologies on October 9-10, 2003, in Washington, D.C., and a workshop on sensing and positioning technologies on October 27-28,2003, in Washington, D.C. Proceedings of those workshops were prepared by an outside rapporteur, and are publicly available. Using sponsor briefings and the workshop proceedings, the Committee identified 23 topical areas in which it believed nanotechnology could contribute materially to IC mission capabilities (Task 2). Assessments of these topics, along with associated findings and recommendations, comprise the final report of this study, which can be accessed at: http://www.jicrd.cia.gov/papers/reportslindex.htm. The unclassified version of this final report is presented here. Biographical sketches of Committee members are given in Appendix A.

EXECUTIVE SUMMARY

Since it was formed at the start of the Cold War with the National Security Act of 1947, the intelligence community (IC) has valued technological creativity, and this interest in technology led to generations of satellites and sensor systems that played a crucial role during that period of conflict. The Cold War is now over, and the IC faces a new set of problems, with greater emphasis on human intelligence, small groups of target individuals, nonstate entities, hard targets such as caves or underground bunkers, unconventional weapons, and regions to which it has very limited access. These new challenges are prompting the IC to rethink its requirements, to try to understand what science and technology tools are now-and will beavailable, and to develop a strategy for analyzing, identifying, and exploiting new technologies.

The current excitement about nanotechnology is based on its potential to bring evolutionary or, in some cases, revolutionary change to a number of fields. Worldwide, government investments in nanoscience and early-stage nanotechnology now exceed $3 billion per year. New capabilities will certainly emerge from this effort, with which the IC must stay current, both for offensive and defensive reasons. However, IC investments should be made with caution; some of the predicted capabilities appear to be realistic, while others are highly speculative or specious.

FINDINGS AND RECOMMENDATIONS

The committee's overall findings and recommendations are as follows:

Finding 1: True nanoscale devices (i.e., those with dimensions <100 nm) that take advantage of quantum and other phenomena offer exciting possibilities for future IC applications. These are currently much closer to the research laboratory than to the production line. Nevertheless, the broader field of "small" technologies (i.e., those undetectable to the naked eye) offers useful nearer-term capabilities.

Recommendation 1: Opportunities exist within a wide range of these small technologies (termed "smalltech" in this report) and are not exclusively in the category of true nanotechnologies. Promising areas of smalltech in which investments could yield useful capabilities in the next 3 to 5 years include, but are not limited to, the following:

- *Next-generation (nanoscale) electronics.* This includes enhanced power sources that may take advantage of nanoscale material architectures for electrodes, battery separators, fuel cell catalysts, etc., as well as for the electronic devices themselves (e.g., moving to 50-nm circuit design rules, more efficient integrated circuits requiring less power to operate, and conformal organic electronics).
- *Technologies that take advantage of the special characteristics of nanostructured materials for sensing and measurement.*

Finding 2: With the transition from the Cold War to the War on Terror, the IC faces a new set of challenges in covertly gathering intelligence on a range of new adversaries in new environments.

Because of the IC's unique requirements, it is unlikely that the research necessary to exploit some opportunities will be fully funded by the private sector; instead some form of direct participation by the IC will be needed.

Recommendation 2: The IC should develop a strategy for exploiting smalltech areas of special promise mentioned in this report. The strategy should include:

- *Search for quasi-commercial technologies.* In these technologies, the costs of development have already largely been paid, but the technologies have not become widely disseminated. Novel applications of dual-use technologies should also be sought.
- *Develop a methodologyfor producing non-commercial technologiesfor use by the IC.* The IC may need its own fabrication facilities to produce smalltech items whose characteristics are not in demand in the commercial sector. It may also wish to facilitate the development of products of unique interest to the IC by small companies and organizations.
- *Develop a mechanism for monitoring and supporting enabling technologies for smalltech breakthroughs.* These include materials science, modeling, and computational science, as well as tools for the manipulation, characterization, and fabrication of nanostructures.
- *Build up long-term, in-house technical expertise in areas related to smalltech; in the near term, seek expert advice regarding investments in areas of high technical risk or uncertainty.* Examples include quantum computing and communication, molecular electronics, and intelligent sensor networks. This expert advice will also help the IC to avoid investing in "science fiction"[1] areas such as nonbiological exponential manufacturing systems (assemblers).

Finding 3: To take advantage of the opportunities discussed in this report, the IC will have to address a variety of technical and economic issues. These include:

- *Defining its own role in the research, development, andfabrication of noncommercial technologies.* For example, if the IC wishes to develop true nanoscale electronics, it will have to develop a strategy for managing the resources needed to make these devices.
- *Globalization.* Government investment in nanotechnology is roughly equal in the United States, the European Union, and Japan; and China, Switzerland, and Israel have intensive programs as well. The IC will need a policy to deal with a situation in which it may be playing catch-up with other countries in some important applications of smalltech.
- *Industrial capabilities.* To stay abreast of the development of the technology-and the capabilities that it provides-it will be necessary to actively monitor industrial R&D abroad.
- *Ultralarge databases.* As nanoscale technology enables information storage to become very small and inexpensive, the ability to store very large amounts of information will soar.

[1] In this report, the Committee uses the phrase "science fiction" to describe those concepts that are sufficiently improbable, based on known or foreseeable science, that they do not justify investment at this time.

TIMING OF TECHNOLOGY DEPLOYMENT

The timing for the deployment of these technologies will depend on a number of factors. Progress will undoubtedly be affected by the level of private effort for "dual use" technologies of interest to, and under development by, both government and private customers. The level of private effort is related to economic factors, including available alternatives, potential market, and opportunity costs. Economic analyses of this kind were beyond the scope of this study and conclusions dependent on them are not included in this report.

Technologies of use for intelligence activities may also be under internal development by the sponsor or other government agencies such as the Defense Advanced Research Projects Agency (DARPA) or the other branches of DOD. Other agencies such as the Department of Energy (DOE), the National Aeronautics and Space Administration (NASA), the Federal Aviation Administration (FAA), and the National Oceanographic and Atmospheric Administration (NOAA) may be developing technologies that could also prove valuable to the mission of the intelligence community. Federal nano R&D efforts are organized and coordinated under the National Nanotechnology Initiative,[2] established in 2000.[3]

While the Committee did receive some information about internal government technology development programs, these were illustrative rather than an exhaustive presentation of the federal government's technology portfolio. It is therefore inappropriate for the Committee to make definitive conclusions about the timing for the deployment of various technologies.

Nevertheless, it is possible to make some qualitative statements about the timing for the deployment of technologies discussed in this report. The Committee expects that quantum computing, molecular electronics, functional nanostructures (e.g., bio-nano supramolecules), and millimeter-scale intelligent distributed sensor networks will probably require longer development times than nano- and organic electronics, nanotaggants, and microbiotechnology based on microfluidic systems.

CONCLUSION

The nanoscale concept will be a unifying theme connecting science and technology globally, and given the amount of effort and money being devoted to it, it is very likely to produce important new technologies. Having said that it is *important,* however, it is also useful to get an idea of *how* important. While the field has produced several revolutionary research tools (e.g., scanning probe microscopes), the Committee remains skeptical of claims that nanotechnology will have the kind of broad, revolutionary impact that has characterized fields such as biotechnology or microelectronics.

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[2] The NNI website is www.nano.gov

[3] National Academy Press, *Small Wonders and Endless Frontiers:* A *Review* of *the National Nanotechnology Initiative,* National Academy Press, Washington, D.C., 2002.

Appendix A: Biographies of Committee Members

Robert J. Hermann, NAE, *Chair,* is currently a senior partner at Global Technology Partners, LLC, a Boston-based firm specializing in investments in technology, defense, aerospace, and related businesses worldwide. In 1998, Dr. Hermann retired from United Technologies Corporation, where he was senior vice president, science and technology. Prior to joining UTC in 1982, Dr. Hermann served 20 years with the National Security Agency, with assignments in research and development, operations, and the North Atlantic Treaty Organization (NATO). In 1977, he was appointed principal deputy assistant secretary of defense for communications, command, control, and intelligence. In 1979, he was named Assistant Secretary of the Air Force for research, development, and logistics and in parallel was director of the National Reconnaissance Office. He received B.S., M.S., and Ph.D. degrees in electrical engineering from Iowa State University. He was a member of the President's Foreign Intelligence Advisory Board from 1993 to 2001 and a chairman of the board of directors of the American National Standards Institute from 1998 to 2000. Dr. Hermann was also chair of the board of directors of Draper Laboratory. He is currently a member of the board of directors of Condor Systems, a member of NAE, and a member of the Defense Science Board.

Antonio A. Cantu is the chief research scientist of the Forensic Services Division of the United States Secret Service. His forensic interests include the chemical analysis of inks and paper on documents for determining their date and origin; the visualization of latent fingerprints using chemical, optical, and physical methods; and the optical and chemical tagging of targets for tracking and locating them. He has assisted in developing countermeasures against threats involving chemical, biological, radiological, nuclear, and explosive (CBRNE) materials. The latter includes technology for point detection and standoff detection of explosives. He co-chairs the Investigative Support and Forensic Subgroup of the Technical Support Working Group (the technical arm of the Interagency Working Group on Counter Terrorism). He has held positions at the U.S. Department of Justice, the Bureau of Alcohol, Tobacco and Firearms, and the FBI. Since 1986, he has been with the U.S. Secret Service. Dr. Cantu received a B.Sc. (1963) and a Ph.D. (1967) in chemical physics from the University of Texas, Austin. He was a postdoctoral fellow at the University of Alberta, Edmonton, and an OAS visiting fellow at the University of Mexico (1970).

James J. DeYoreo is currently acting director, Bio-Security and Nanosciences Laboratory of the Lawrence Livermore National Laboratory's Chemistry and Materials Science Directorate. His research interests include scanned probe nanolithography, nanoscale surface patterning, nucleation templates, physics of crystal surfaces in solutions, macromolecular crystallization, biomineralization, interaction of organic molecules with inorganic crystal surfaces, assembly of supramolecular motifs, high-resolution imaging, physics and chemistry of crystalline defects, and characterization of optical crystals. Dr. De Yoreo is a member of the Materials Research Society and vice president of the American Association for Crystal Growth. In 1994 he was presented the R&D 100 award—Development of rapid growth process for KDP, and in 2001 he received the Lawrence Livermore National Laboratory Science and Technology

Award. Dr. De Yoreo earned a B.A in physics from Colby College and an M.S. and Ph.D. in experimental physics from Cornell University.

Daniel H. Doughty received his Ph.D. in inorganic chemistry from the University of Minnesota in 1979. His thesis work explored the synthesis, characterization, and mechanistic study of organometallic complexes used in homogeneous decarboxylation catalysis. He studied various compounds, primarily in the family of rhodium phosphine complexes. He also studied at the Catholic University of America and the University of New Mexico, where he obtained a B.S. in chemistry and an M.S. in inorganic chemistry. Dr. Doughty currently is the manager of the Lithium Battery Research and Development Department, Sandia National Laboratories. This group has responsibility for developing advanced power sources, typically batteries and electrochemical cells based on lithium. Areas of expertise include various lithium chemistries (e.g., lithium-ion rechargeable batteries and lithium thionyl chloride cells and batteries). The group works on cutting-edge electrochemistry as well as advanced batteries and battery materials for defense and commercial applications. Prior to taking this assignment in 1992, he led the Inorganic Materials Chemistry Division for 7 years. This group has responsibility for advanced ceramic and glass materials as well as general inorganic chemistry. Specifically, the preparation of preceramic materials was a major effort that used sol-gel chemistry and other solution routes to ceramic and glass materials. Previous projects at Sandia National Laboratories involved organometallic chemistry, inorganic chemistry, nanostructured gold colloids, and the kinetics of gas-solid reactions. Prior to joining Sandia, Dr. Doughty worked for 3 years at 3M Company as a research chemist developing advanced inorganic photoconductors. Other areas of interest are general materials chemistry and processing, including colloid chemistry, superconducting ceramics, intercalation compounds, and oxide surface chemistry. Dr. Doughty received the DOE Award of Excellence in 1989 and is a member of the American Chemical Society, the Materials Research Society, ECS, and Phi Kappa Phi honorary fraternity. He has over 80 publications, holds three patents, and has co-edited four technical proceedings volumes.

Lawrence H. Dubois received an S.B. degree in chemistry from the Massachusetts Institute of Technology in 1976 and a Ph.D. in physical chemistry from the University of California, Berkeley, in 1980. Dr. Dubois then joined AT&T Bell Laboratories to pursue studies of the chemistry and physics of metal, semiconductor, and insulator surfaces; chemisorption and catalysis by materials formed at the metal-semiconductor interface; and novel methods of materials growth and preparation. In 1987, he was promoted to distinguished member of the technical staff and technical manager. His efforts broadened to include projects on polymer-surface interactions; adhesion promotion; corrosion protection; chemical vapor deposition and thin-film growth; optical fiber coating; synthesis, structure, and reactivity of model organic surfaces; and time-resolved surface vibrational spectroscopy. In 1993, Dr. Dubois moved to MIT Lincoln Laboratory as a senior staff scientist and was assigned to the Defense Advanced Research Projects Agency (DARPA). In that capacity, he established the Advanced Energy and Environmental Technologies Program and managed projects on the development and manufacturing of rechargeable batteries; high-performance, direct-methanol, and logistic-fuel-powered fuel cells; and the development of new, more environmentally sound manufacturing processes, environmental sensors, and waste destruction/reclamation procedures. In 1995, Dr. Dubois was promoted to deputy director and in 1996 to director of the Defense Sciences Office at DARPA. This office is responsible for an annual investment of approximately $300 million for the development of technologies for biological warfare defense, biology, defense applications of advanced mathematics and materials, and devices for new military capabilities. In March 2000, Dr. Dubois joined SRI International as corporate vice president and head of the Physical Sciences Division, a group of over 150 scientists and engineers focusing on the development and commercialization of advanced materials, microfabrication technologies, power sources, biological warfare defense, medical diagnostics, molecular and optical physics, explosives and propellants, catalysts, coatings, and environmentally benign processing. Dr. Dubois is the author of over 130 publications and holds four U.S. patents and several foreign patents. His numerous honors include the prestigious IR100 and Alpha Chi Sigma awards as well as the Office of the Secretary of Defense Award for Outstanding Achievement and the Secretary of Defense Medal for Outstanding Public Service. He sits on the board of directors of two spin-off companies from SRI: Polyfuel and CYANCE.

Alan H. Epstein, NAE, is currently R. C. Maclaurin Professor at the Massachusetts Institute of Technology, Department of Aeronautics and Astronautics. He is also the head of the Division of Fluids, Propulsion and Energy Conversion. He is responsible for teaching gas turbine and rocket engine design at the undergraduate and graduate level; coordinating teaching, graduate admissions, and faculty staffing for fluid mechanics, propulsion, and energy conversion; directing the 80-person MIT Gas Turbine Laboratory; serving as principal investigator and director of the 50-person MIT MicroEngine Project; and conducting research on advanced propulsion and energy conversion technologies. His interests include teaching and research in the areas of compressor and turbine aerodynamics, compressor stability, turbine engine controls, turbine heat transfer, engine instrumentation and measurement, turbomachinery noise, and microengines and MEMS. Dr. Epstein's consulting activities include gas turbine engine design and design practice; engineering management and organization; and signature analysis of air-breathing vehicles. In addition to being a member of the National Academy of Engineering, Dr. Epstein also holds membership in the American Association for the Advancement of Science and the American Society of Mechanical Engineers, as well as being a fellow at the American Institute of Aeronautics and Astronautics. He has been a liaison, chair, and member of numerous National Research Council committees and boards, including committees for the Review of ONR's Aircraft Technology Program, Implications of Micro and Nanotechnology for the U.S. Air Force, and Review of Effectiveness of U.S. Air Force S&T Changes, and the Board on Army Science and Technology. Dr. Epstein received his B.S., M.S., and Ph.D. degrees from the Massachusetts Institute of Technology and has over 90 publications in the fields of gas turbine technology, air vehicle observables, instrumentation development, and MEMS.

Wilhelm B. Gauster is currently deputy director of the Physical and Chemical Sciences Center at Sandia National Laboratories, where he manages nanoscience activities for defense program applications. His own research has covered a wide range of topics in solid-state physics and nuclear technology, including thermomechanics, optical properties of semiconductors, neutron and electron irradiation effects, positron annihilation, muon spin rotation, plasma-materials interactions, and high-heat-flux components for fusion devices. He has managed a variety of programs in basic and applied research, fission and fusion technology, and energy policy. Dr. Gauster received an A.B. in applied physics from Harvard College and a Ph.D. in physics from the University of Tennessee. He has served as a member of numerous editorial boards and advisory panels, as an adjunct professor at the University of New Mexico, visiting scientist at the Jülich Research Center, and deputy head of site at the International Thermonuclear Experimental Reactor Joint Work Site in Garching (Germany). He was a member of the Department of Energy Magnetic Fusion Advisory Committee in 1988 and 1989 and received the Department of Energy Distinguished Associate Award in 1993.

Shirley A. Jackson, NAE, is currently the president of Rensselaer Polytechnic Institute. Her career prior to becoming Rensselaer's president encompassed senior positions in government, as chairman of the U.S. Nuclear Regulatory Commission; in industry and research, as a theoretical physicist at the former AT&T Bell Laboratories; and in academe, as a professor of theoretical physics at Rutgers University. Dr. Jackson holds a Ph.D. in theoretical elementary particle physics from MIT and an S.B. in physics from MIT. Her research specialty is in theoretical condensed-matter physics, especially layered systems, and the physics of opto-electronic materials. In 1995 President Clinton appointed Dr. Jackson to serve as chair of the U.S. Nuclear Regulatory Commission, which position she occupied from 1995 to 1999. As chair, she was the principal executive officer of and the official spokesman for the Nuclear Regulatory Commission. From 1991 to 1995, Dr. Jackson was professor of physics at Rutgers University, where she taught undergraduate and graduate students, conducted research on the electronic and optical properties of two-dimensional systems, and supervised Ph.D. candidates. She concurrently served as a consultant in semiconductor theory to AT&T Bell Laboratories. Dr. Jackson will become president of the American Association for the Advancement of Science (AAAS) in February 2004. She will chair the AAAS board in 2005. Dr. Jackson is a member of the National Academy of Engineering and a fellow of the American Academy of Arts and Sciences and the American Physical Society. Dr. Jackson holds 21 honorary doctoral degrees. She is a member of the National Advisory Council for Biomedical Imaging and Bioengineering of the National Institutes of Health (NIH), serves on the Advisory Committee for the Department of Energy National Nuclear Security Administration (NNSA), and is a member of the U.S. Comptroller-General's Advisory Committee for the Government Accounting Office (GAO). She also has served on a number of committees of the National Research Council of the National Academies.

Siegfried W. Janson is a senior scientist at the Aerospace Corporation. He obtained a Ph.D. in aerospace engineering from Cornell University in 1984. He was a postdoctoral associate at Cornell from 1984 to 1987, at which time he joined the Aerospace Corporation to pursue experimental research in electric thrusters and advanced laser-based propulsion diagnostics. Dr. Janson's current research interests are micropropulsion, micro/nanotechnology for space systems, formation flying, and distributed space systems. He has worked in the MEMS field for 13 years and authored or co-authored over 20 papers on microthrusters, micro/nanotechnology for space applications, and silicon satellites. He managed and co-managed two DARPA-sponsored MEMS programs (Digital Thrusters and Micro Power

Generator) and participated in MEMS flight experiments on the shuttle and the International Space Station. Dr. Janson has given invited presentations on micro/nanotechnology for spacecraft to the National Academy of Engineering, the European Space Agency, and the International Space University. He was co-chair (2001) and chair (2003) of the SPIE conference MEMS Components and Applications for Industry, Automobiles, Aerospace, and Communications. Dr. Janson has served on several NRC panels for the review of Air Force Office of Scientific Research propulsion proposals and on the NRC Committee on Implications of Emerging Micro and Nano Technologies. He is a member of the IEEE and a senior member of the American Institute of Aeronautics and Astronautics (AIAA).

Anthony F. Laviano is a member of the Raytheon Space and Airborne Engineering staff in El Segundo, California. He is a member of the Patent Committee and is program manager for Advanced Technical Programs. His focus is advanced technologies and products, which include power electronics; sensor, processor and antenna technologies; and dual-use applications—that is, he identifies, organizes, and transitions technology into both military and commercial application. He established and is the leader of the Nano Engineering and Science Technology Interest Group. He led and facilitated the Power Electronics Technology Interest Group; represents engineering in industry endeavors such as the Open Systems Joint Task Force for Power Electronics through the U.S. Air Force; is the Power Sources Manufacturer's Association chairperson for the Industry Government Committee; and is co-leader of the Electronic Power Specification Standardization Industry Working Group, which writes power electronics standards under IEEE auspices. He is past chairman of the IEEE Power Electronics Society for Southern California, a member of the IEEE Standards Association, the IEEE Los Angeles Council, the IEEE Wescon, and the Academy of Management, and is on the editorial board of the *Journal of Public Administration*. He is a certified contracts manager and a National Contract Association fellow. He received a Ph.D. in business administration from Nova Southeastern University, Florida, an M.B.A. from Pepperdine University, and a B.A. from St. Charles College, Pennsylvania, and graduated from the U.S. Army Language School as a Chinese linguist. He is a former member of the National Faculty of Nova Southeastern University Graduate School of Business and Entrepreneurship, as well as the Hughes Aircraft Company technology staff. His technical involvement includes nanotechnology, antenna development, data and mission processors, power electronics, radar systems, software development, system architecture, terrestrial communication systems, and satellite communication systems.

Debra R. Rolison is currently the section head of Advanced Electrochemical Materials at the Naval Research Laboratory. Before this position, Dr. Rolison was a research chemist at the Naval Research Laboratory. She is also an adjunct professor of chemistry at the University of Utah. Her research interests include synthesis and characterization of nanostructured materials, including research into processes occurring at the electrified interfaces of nanostructured materials with emphasis on (1) aerogels; (2) supported electrocatalysts and nanoscale electrodes; (3) zeolites; (4) colloids; (5) dispersions of catalytically active solids; and (6) chemically modified and dimensionally structured electrode surfaces. A recent research focus has been nanoarchitectures for catalytic chemistries, energy storage and conversion, biomolecular composites, porous magnets, and sensors. Principal inventions include (1) electrified microheterogeneous catalysis; (2) using silica sol as a nanoglue to synthesize composite gels and aerogels; (3) electrodesulfurization of solid carbon; (4) creating a three-dimensional nanowired mesoporous architecture; and (5) infrared-emitting materials. Dr. Rolison also writes and lectures widely on issues affecting women in science. Her ideas with respect to using Title IX to evaluate academic science and engineering departments recently led to a hearing on Title IX and the sciences before the U.S. Senate Subcommittee on Science, Technology, and Space. Dr. Rolison is a member of the American Chemical Society, the Materials Research Society, and the Society for Electroanalytical Chemistry; she was elected a fellow of the AAAS in 2001. She coauthored *Ultramicroelectrodes,* the first text on this active area, with M. Fleischmann, S. Pons, and P. Schmidt. She guest edited an issue of *Langmuir* devoted to the electrochemistry of nanostructured materials and recently served as a guest editor of a *Journal of Physical Chemistry* Festschrift in honor of Royce Murray. Her past and present editorial advisory board service includes *Analytical Chemistry, Langmuir, Journal of Electroanalytical Chemistry, Nano Letters,* and the *Encyclopedia of Nanoscience and Nanotechnology*. She was a member of the board of directors of SEAC and served as editor of *SEAC Communications*. Dr. Rolison was named the 2003 Woman of Excellence by the University of Delaware. She chaired the 2001 Gordon Research Conference on Electrochemistry and the 2003 International Symposium on Aerogels. She received a Ph.D. from the University of North Carolina. She has published over 60 papers and holds 14 patents.

R. Paul Schaudies is a nationally recognized expert in the fields of biological and chemical warfare defense. He has served on numerous national-level advisory panels for the Defense Intelligence Agency, the Defense Advanced Research Projects Agency, and the Department of Energy. He has 14 years' bench research experience managing laboratories at Walter Reed Hospital and Walter Reed Army Institute of Research and was a visiting scientist at the National Cancer Institute. He served for 13 years on active duty with the Army Medical Service Corps, and separated from service at the rank of Lieutenant Colonel-select. Dr. Schaudies spent 4 years with the Defense Intelligence Agency as collections manager for biological and chemical defense technologies. As such, he initiated numerous intra-agency collaborations that resulted in accelerated product development in the area of biological warfare agent detection and identification. Dr. Schaudies is currently an assistant vice president and division manager of the Biological and Chemical Defense Division at SAIC. His division focuses on three major business areas: contract biomedical research, technology assessments, and scientific studies. Since joining SAIC, Dr. Schaudies has served on and chaired numerous technology review and advisory panels for U.S. government agencies. Dr. Schaudies received his bachelor's degree in chemistry from Wake Forest University and his doctoral degree from Temple University School of Medicine in the Department of Biochemistry. He has authored 27 scientific manuscripts in the peer-reviewed literature, as well as three book chapters. Dr. Schaudies is active in both government and academic circles.

Julia R. Weertman, NAE, has conducted research on the mechanical behavior of metals and alloys and the underlying phenomena that give rise to the observed behavior. Her research currently focuses on determining the mechanical properties of a variety of nanocrystalline materials, characterizing their structure, and studying deformation mechanisms in this smallgrain-size regime. She also continues interest in the high-temperature behavior of metals. Her research has demonstrated the value of small-angle neutron scattering for detection and quantification of such features as voids and pores and for following the nucleation and growth kinetics of second-phase particles. Dr. Weertman is a member of the National Academy of Engineering and the American Academy of Arts and Sciences. She is past member of the Committee on Women in Science and Engineering and of the Committee on Human Rights of the National Academies and has served on several NRC panels. Currently she is a member of the NRC National Materials Advisory Board. She has served on advisory panels for DOE and NSF and for several national laboratories. She is on the board of review editors for *Science*. She is a fellow of the Materials Society and ASM International, received Special Creativity Awards for Research from NSF in 1981 and 1986, a Guggenheim Fellowship in 1986–1987, the Achievement Award from the Society of Women Engineers in 1991, and the Leadership Award from the Materials Society in 1997.

George M. Whitesides, NAS, received an A.B. degree from Harvard University in 1960 and a Ph.D. from the California Institute of Technology (with J. D. Roberts) in 1964. He was a member of the faculty of the Massachusetts Institute of Technology from 1963 to 1982. He joined the Department of Chemistry of Harvard University in 1982, and was department chairman from 1986 to 1989. He is now Mallinckrodt Professor of Chemistry at Harvard University. He received an Alfred P. Sloan Fellowship in 1968; the American Chemical Society (ACS) Award in Pure Chemistry in 1975; the Harrison Howe Award (Rochester Section of the ACS) in 1979; an Alumni Distinguished Service Award (California Institute of Technology) in 1980; the Remsen Award (ACS, Maryland Section) in 1983; an Arthur C. Cope Scholar Award (ACS) in 1989; the James Flack Norris Award (ACS, New England Section) in 1994; the Arthur C. Cope Award (ACS) in 1995; the Defense Advanced Research Projects Agency Award for Significant Technical Achievement in 1996; the Madison Marshall Award (ACS) in 1996; the National Medal of Science in 1998; the Sierra Nevada Distinguished Chemist Award (Sierra Nevada Section of the ACS); the Wallac Oy Innovation Award in High Throughput Screening (the Society for Biomolecular Screening) in 1999; the Award for Excellence in Surface Science (Surfaces in Biomaterials Foundation) in 1999; and the Von Hippel award (Materials Research Society) in 2000. He is a member of the American Academy of Arts and Sciences, the National Academy of Sciences, and the American Philosophical Society. He is also a fellow of the American Association for the Advancement of Science and the New York Academy of Science, a foreign fellow of the Indian National Science Academy, and an honorary fellow of the Chemical Research Society of India.

Ellen D. Williams is currently a professor in the Department of Physics and the Institute for Physical Science and Technology at the University of Maryland, as well as the director of the Materials Research Science and Engineering Center. Dr. Williams is a fellow of the American Academy of Arts and Sciences. In 2001 she was the recipient of the American Physical Society's David Adler Lectureship Award, and in 1998–1999, she was its centennial speaker. Dr. Williams serves on the National Security Panel of the University of California President's Council and is also on the editorial board of *Nano Letters* (ACS). Dr. Williams received a B.S. in chemistry from Michigan State University and a Ph.D. in chemistry from the

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Mary H. Young is the director of the Sensors and Materials Laboratory of Hughes Research Laboratories, a research company that is jointly owned by Boeing, General Motors, and Raytheon Company. Dr. Young manages an organization with research emphasis in microelectromechanical and nanofabrication technologies, energy technologies, electro-optical sensor materials and process technologies, materials engineering, and nanoelectronics. Dr. Young received her B.S. in physics at Wake Forest University, her M.S. in physics at the University of Maryland, and her Ph.D. at UCLA in electrical engineering. Since joining Hughes Research Laboratories in 1974, Dr. Young has conducted research on the development of ultrapure silicon, extrinsic semiconductors for use in IR detector programs, GaAs for a variety of electronic and optical device applications, superconductors for microelectronics, and superlattice materials for novel device concepts. Currently, she is engaged in directing the development of novel processes for materials, including semiconductors, active materials, materials for thermal management, and materials for energy and power, and in exploring innovative sensor types and designs, including MEMS devices, chemical and biological threat/environmental sensors, electromagnetic sensors, and multisensor control methodologies. Major application programs in energy storage and conversion, materials for automotive/aerospace sensors and power systems, semiconductor nanoelectronics, MEMS-based sensor and communications systems, and IR sensor-based systems are among the programs currently being conducted under the direction of Dr. Young. Dr. Young has contributed original work in electronic transport physics in semiconductors and in the physics of IR-sensitive materials and IR devices and managed a number of IR sensor development programs. From 1971 to 1974 she was manager of an analytic facility for the Materials Research Laboratory at the University of Maryland. Dr. Young is a member of Phi Beta Kappa and of the American Physical Society and the Materials Research Society. She has more than two dozen publications on semiconductor materials, infrared detectors, impurity hopping electronic transport, neutron transmutation in semiconductors, and superlattice materials and devices.