

**RESEARCH ON ENVIRONMENTAL AND
SAFETY IMPACTS OF NANOTECHNOLOGY:
WHAT ARE THE FEDERAL AGENCIES DOING?**

HEARING
BEFORE THE
COMMITTEE ON SCIENCE
HOUSE OF REPRESENTATIVES
ONE HUNDRED NINTH CONGRESS

SECOND SESSION

SEPTEMBER 21, 2006

Serial No. 109-63

Printed for the use of the Committee on Science



Available via the World Wide Web: <http://www.house.gov/science>

U.S. GOVERNMENT PRINTING OFFICE

29-852PS

WASHINGTON : 2006

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov Phone: toll free (866) 512-1800; DC area (202) 512-1800
Fax: (202) 512-2250 Mail: Stop SSOP, Washington, DC 20402-0001

COMMITTEE ON SCIENCE

HON. SHERWOOD L. BOEHLERT, New York, *Chairman*

RALPH M. HALL, Texas	BART GORDON, Tennessee
LAMAR S. SMITH, Texas	JERRY F. COSTELLO, Illinois
CURT WELDON, Pennsylvania	EDDIE BERNICE JOHNSON, Texas
DANA ROHRABACHER, California	LYNN C. WOOLSEY, California
KEN CALVERT, California	DARLENE HOOLEY, Oregon
ROSCOE G. BARTLETT, Maryland	MARK UDALL, Colorado
VERNON J. EHLERS, Michigan	DAVID WU, Oregon
GIL GUTKNECHT, Minnesota	MICHAEL M. HONDA, California
FRANK D. LUCAS, Oklahoma	BRAD MILLER, North Carolina
JUDY BIGGERT, Illinois	LINCOLN DAVIS, Tennessee
WAYNE T. GILCHREST, Maryland	DANIEL LIPINSKI, Illinois
W. TODD AKIN, Missouri	SHEILA JACKSON LEE, Texas
TIMOTHY V. JOHNSON, Illinois	BRAD SHERMAN, California
J. RANDY FORBES, Virginia	BRIAN BAIRD, Washington
JO BONNER, Alabama	JIM MATHESON, Utah
TOM FEENEY, Florida	JIM COSTA, California
RANDY NEUGEBAUER, Texas	AL GREEN, Texas
BOB INGLIS, South Carolina	CHARLIE MELANCON, Louisiana
DAVE G. REICHERT, Washington	DENNIS MOORE, Kansas
MICHAEL E. SODREL, Indiana	DORIS MATSUI, California
JOHN J.H. "JOE" SCHWARZ, Michigan	
MICHAEL T. MCCAUL, Texas	
MARIO DIAZ-BALART, Florida	

CONTENTS

September 21, 2006

Witness List	Page 2
Hearing Charter	3

Opening Statements

Statement by Representative Sherwood L. Boehlert, Chairman, Committee on Science, U.S. House of Representatives	22
Written Statement	23
Statement by Representative Bart Gordon, Minority Ranking Member, Com- mittee on Science, U.S. House of Representatives	24
Written Statement	25
Prepared Statement by Representative Jerry F. Costello, Member, Committee on Science, U.S. House of Representatives	26
Prepared Statement by Representative Daniel Lipinski, Member, Committee on Science, U.S. House of Representatives	26

Witnesses:

Dr. Norris E. Alderson, Chair, Nanotechnology, Environmental, and Health Implications Working Group; Associate Commissioner for Science, Food and Drug Administration	
Oral Statement	28
Written Statement	30
Biography	32
Dr. Arden L. Bement, Jr., Director, National Science Foundation	
Oral Statement	32
Written Statement	34
Biography	39
Dr. William H. Farland, Deputy Assistant Administrator for Science, Office of Research and Development, U.S. Environmental Protection Agency	
Oral Statement	40
Written Statement	42
Dr. Altaf H. (Tof) Carim, Program Manager, Nanoscale Science and Electron Scattering Center, U.S. Department of Energy	
Oral Statement	45
Written Statement	46
Biography	49
Dr. Andrew D. Maynard, Chief Science Advisor, Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars	
Oral Statement	50
Written Statement	51
Biography	63
Financial Disclosure	64
Mr. Matthew M. Nordan, President, Director of Research, Lux Research, Inc.	
Oral Statement	65
Written Statement	67
Biography	73

IV

	Page
Discussion	
Coordinating Federal Environmental, Health, and Safety Nanotechnology Research Programs	74
Regulatory Structure for University and Industry Nanomaterial Research ...	79
Is the Marketplace Outrunning Research?	80
Setting Priorities	81
Public Awareness of Nanotechnology	82

Appendix 1: Answers to Post-Hearing Questions

Dr. Norris E. Alderson, Chair, Nanotechnology, Environmental, and Health Implications Working Group; Associate Commissioner for Science, Food and Drug Administration	86
Dr. Arden L. Bement, Jr., Director, National Science Foundation	93
Dr. William H. Farland, Deputy Assistant Administrator for Science, Office of Research and Development, U.S. Environmental Protection Agency	99
Dr. Altaf H. (Tof) Carim, Program Manager, Nanoscale Science and Electron Scattering Center, U.S. Department of Energy	102
Dr. Andrew D. Maynard, Chief Science Advisor, Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars	105

Appendix 2: Additional Material for the Record

<i>Environmental, Health, and Safety Research Needs for Engineered Nanoscale Materials</i> , Nanoscale Science, Engineering, and Technology Subcommittee, Committee on Technology, National Science and Technology Council, September 2006	112
--	-----

**RESEARCH ON ENVIRONMENTAL AND SAFETY
IMPACTS OF NANOTECHNOLOGY: WHAT
ARE THE FEDERAL AGENCIES DOING?**

THURSDAY, SEPTEMBER 21, 2006

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE,
Washington, DC.

The Committee met, pursuant to call, at 10:05 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Sherwood L. Boehlert [Chairman of the Committee] presiding.

**COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES**

*Research on Environmental and Safety Impacts of Nanotechnology:
What Are the Federal Agencies Doing?*

Thursday, September 21, 2006
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building (WEBCAST)

Witness List

Dr. Norris E. Alderson,
Chair of Nanotechnology
Environmental and Health Implications Working Group
Associate Commissioner for Science
Food and Drug Administration

Dr. Arden L. Bement, Jr.
Director
National Science Foundation

Dr. William Farland
Deputy Assistant Administrator for Science
Office of Research and Development
U.S. Environmental Protection Agency

Dr. Altaf H. (Tof) Carim
Program Manager, Nanoscale Science and Electron Scattering Center
U.S. Department of Energy

Mr. Matthew M. Nordan
President, Director of Research
Lux Research, Inc.

Dr. Andrew Maynard
Chief Science Advisor, Project on Emerging Nanotechnologies
Woodrow Wilson International Center for Scholars

Section 210 of the Congressional Accountability Act of 1995 applies the rights and protections covered under the Americans with Disabilities Act of 1990 to the United States Congress. Accordingly, the Committee on Science strives to accommodate/meet the needs of those requiring special assistance. If you need special accommodation, please contact the Committee on Science in advance of the scheduled event (3 days requested) at (202) 225-6371 or FAX (202) 225-0891.

Should you need Committee materials in alternative formats, please contact the Committee as noted above.

HEARING CHARTER

**COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES**

**Research on Environmental and
Safety Impacts of Nanotechnology:
What Are the Federal Agencies Doing?**

THURSDAY, SEPTEMBER 21, 2006
10:00 A.M.—12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

1. Purpose

On Thursday, September 21, 2006, the Committee on Science of the House of Representatives will hold a hearing to examine whether the Federal Government is adequately funding, prioritizing, and coordinating research on the environmental and safety impacts of nanotechnology.

2. Witnesses

Dr. Norris E. Alderson is the Chair of the interagency Nanotechnology Environmental and Health Implications Working Group and the Associate Commissioner for Science at the Food and Drug Administration (FDA).

Dr. Arden L. Bement, Jr. is the Director of the National Science Foundation (NSF).

Dr. William Farland is the Deputy Assistant Administrator for Science in the Office of Research and Development at the Environmental Protection Agency (EPA).

Dr. Altaf H. (Tof) Carim is a Program Manager in the Nanoscale Science and Electron Scattering Center at the Office of Basic Energy Sciences in the Department of Energy (DOE).

Dr. Andrew Maynard is the Chief Science Advisor for the Project on Emerging Nanotechnologies at the Woodrow Wilson International Center for Scholars.

Mr. Matthew M. Nordan is the President and Director of Research at Lux Research Inc., a nanotechnology research and advisory firm.

3. Overarching Questions

- How much is the Federal Government spending on research on environmental and safety impacts of nanotechnology? How are funding levels determined? Are current federal research efforts adequate to address concerns about environmental and safety ramifications of nanotechnology?
- What are the priorities for federally-supported research on the environmental and safety impacts of nanotechnology? How are these priorities determined, and are the current priorities appropriate?
- What impacts are environmental and safety concerns having on the development of nanotechnology-related products and their entry into the marketplace? What impact might these concerns have in the future?
- Are additional steps needed to improve management and coordination of federal research in this area?

4. Brief Overview

- Nanotechnology, the science of materials and devices of the scale of atoms and molecules, has entered the consumer marketplace. Today, there are over 300¹ products on the market claiming to contain nanomaterials (materials engineered using nanotechnology or containing nano-sized particles), generating

¹Wilson Center, Project on Emerging Nanotechnologies, "Nanotechnology: A Research Strategy for Addressing Risk," July, 2006. p. 4.

an estimated \$32 billion in revenue.² By 2014, according to Lux Research,³ a private research firm that focuses on nanotechnology, there could be \$2.6 trillion worth of products in the global marketplace which have incorporated nanotechnology.

- There is significant concern in industry that the projected economic growth of nanotechnology could be undermined by either real environmental and safety risks of nanotechnology or the public's perception that such risks exist. Recently, some reports have indicated that these concerns are causing some companies to shy away from nanotechnology-related products and downplay nanotechnology when they talk about or advertise their products. There is an unusual level of agreement among researchers, and business and environmental organizations that the basic scientific information needed to assess and protect against potential risks does not yet exist.
- The President's fiscal year 2007 (FY07) budget requests \$1.3 billion for the National Nanotechnology Initiative (NNI), the interagency nanotechnology research and development (R&D) program. Of this amount, the budget proposes \$44.1 million (3.5 percent of the overall program) for research on environmental and safety implications of nanotechnology. This is \$6.6 million above the FY06 funding level. Nearly 60 percent of this funding would go to NSF.
- In October 2003, the White House National Science and Technology Council organized an interagency Nanotechnology Environmental and Health Implications (NEHI) Working Group, composed of agencies with research and regulatory responsibilities for nanotechnology, to coordinate environmental and safety research. The NEHI Working Group is charged with "facilitate[ing] the identification, prioritization, and implementation of research. . . required for the responsible" development and use of nanotechnology.⁴ The Food and Drug Administration serves as the current Chair of the NEHI Working Group.
- One of the NEHI Working Group's initial tasks was developing a report describing research needs for assessing and managing the potential environmental and safety risks of nanotechnology. In March 2006, the Administration informed the Science Committee that this report would be completed that spring, but the document has not yet been released.
- In July 2006, the Wilson Center's Project on Emerging Nanotechnologies released a report proposing a research strategy for "systematically exploring the potential risks of nanotechnology." The report highlights critical federal research that urgently needs to be carried out in the next two years and recommends that a non-governmental organization, such as the National Academy of Sciences, develop and regularly review a long-term research strategy. The report also finds that current federal coordination does not yet have an effective mechanism to set research priorities, distribute tasks among the agencies, and ensure that adequate resources are provided for the most urgent research.

5. Previous Science Committee Hearing

The Science Committee held a previous hearing on this topic, *Environmental and Safety Impacts of Nanotechnology: What Research is Needed?*, on November 17, 2005. The charter for that hearing is attached (Appendix). At that hearing, witnesses from the Federal Government, industry, and environmental organization agreed that relatively little is understood about the environmental and safety implications of nanotechnology. The non-governmental witnesses emphasized that, for the emerging field of nanotechnology to reach its full economic potential, the Federal Government must significantly increase funding for research in this area.

6. Developments Since November 2005

Fiscal Year 2007 Budget

In July 2006, the Administration released its nanotechnology supplement to the President's FY07 budget request.⁵ This document includes information about the

²Lux Research, "Taking Action on Nanotech Environmental, Health, and Safety Risks," Advisory, May 2006 (NTS-R-06-003) (hereafter cited as "Taking Action").

³Lux Research, "Sizing Nanotechnology's Value Chain," October, 2004.

⁴Terms of Reference, Nanotechnology Environmental and Health Implications Working Group Nanoscale Science, Engineering, and Technology Subcommittee Committee on Technology; March, 2005.

⁵The National Nanotechnology Initiative: "Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY 2007 Budget." <http://www.ostp.gov/nstc/html/NNI%2007%20Budget%20Supplement%20July%202007.pdf>

overall funding levels for research on environment and safety impacts of nanotechnology at each of the federal agencies participating in the NNI (see Table 1). The budget supplement also provides brief descriptions of some of the activities underway in this area, and highlights FY07 initiatives such as the expansion of a joint grant program among EPA, NSF, the National Institute for Occupational Safety and Health (NIOSH) and the National Institute of Environmental Health Sciences (NIEHS), but it does not provide funding levels for specific research activities. (NIOSH is part of the Department of Health and Human Services (DHHS), and NIEHS is part of the National Institutes of Health (NIH), also part of DHHS.) To help the agencies determine how to estimate the funding levels reported in Table 1, the National Nanotechnology Coordinating Office provides a definition of “Environment Health, and Safety Implications Research and Development (R&D),” but the agencies’ application of the definition to their programs can vary.

Table 1: NNI Proposed FY07 Investments in Research on Environmental and Safety Implications of Nanotechnology (\$ in millions)

Agency	Total Spending on Nanotechnology R&D (FY07 Proposed)	Environment Health, and Safety Implications R&D (FY07 Proposed)	Percent of Total Environment, Health and Safety Implications R&D
NSF	373.0	25.7	58.3%
DOD	345.0	1.0	2.3%
DOE	258.0	0.0	0.0%
DHHS (NIH)	170.0	4.6	10.4%
DOC (NIST)	86.0	1.8	4.1%
NASA	25.0	0.0	0.0%
EPA	9.0	8.0	18.1%
USDA (CSREES)	3.0	0.1	0.2%
DHHS (NIOSH)	3.0	3.0	6.8%
USDA (FS)	2.0	0.0	0.0%
DHS	2.0	0.0	0.0%
DOJ	1.0	0.0	0.0%
DOT (FHWA)	0.1	0.0	0.0%
TOTAL	1,278.0	44.1	100.0%

Acronyms

CSREES = Cooperative State, Research, and Education Extension Service (within USDA)
DHS = Department of Homeland Security
DOC = Department of Commerce
DOD = Department of Defense
DOJ = Department of Justice
DOT = Department of Transportation
FHWA = Federal Highway and Works Administration (within DOT)
FS = Forest Service (within USDA)
NASA = National Aeronautics and Space Administration
USDA = U.S. Department of Agriculture

Report on Federal Priorities for Research on Environmental and Safety Implications of Nanotechnology Is Not Completed

At the Science Committee’s November 17, 2005 hearing on nanotechnology, Dr. Clayton Teague, Director of the National Nanotechnology Coordination Office, testified that the NEHI Working Group was “preparing a document that identifies and prioritizes information and research needs in this area. The document will serve as a guide to the NNI agencies as they develop budgets and programs and will inform individual investigators as they consider their research directions.”⁶ In his responses to questions for the record, Dr. Teague said the report was expected to be completed by “Spring 2006” and “is intended to be sufficiently detailed to guide investigators and managers in making project-level decisions, yet broad enough to provide a framework for the next five to ten years.” The report has not yet been completed and no drafts have been released for public comment.

⁶Clayton Teague Testimony, November 17, 2005, House Science Committee, p. 3.

For the final document to provide useful guidance to agencies, Congress, industry academic researchers, environmental groups, and the public, it will need to define the scale and scope of the needed research, set priorities for research areas, provide information that can affect agency-directed spending decisions, and be specific enough to serve as overall research strategy for federal and non-federal research efforts. In the absence of such a document, each agency can only set its priorities and funding levels based on its individual mission rather than in the context of other agencies' needs or activities.

Recent Reports

In the past year, five new reports have been published that characterize how the private sector is coping with environmental and safety implications of nanotechnology and how the Federal Government is funding and should be prioritizing its research in this area. Three of the most significant new reports are summarized below.⁷ In addition, this week the Wilson Center released the results of a national poll indicating that the majority of the public still has heard little to nothing about nanotechnology. The poll also finds that the public looks to the Federal Government and independent parties to monitor nanotechnology research and products. These findings bolster earlier calls by Congress, businesses, and environmental groups for the Federal Government to prioritize and provide more support for critical research on understanding the risks associated with nanotechnology so as to inform the public and enable the responsible development of nanotechnology.

Lux Research Report

In May 2006, Lux Research, a business research and advisory firm specializing in nanotechnology, released a report⁸ updating its May 2005 assessment⁹ of the environment and safety landscape for businesses involved with nanotechnology. According to Lux, the debate about the environmental and safety implications of nanotechnology has "intensified," while the continuing lack of data, tools, and protocols for answering key safety questions is creating significant challenges for companies interested in developing nanotechnology-related products and their potential investors.

Some large companies are shying away from nanotechnology-related products because they fear potential liabilities or the costs of extensive toxicity testing. Smaller, nanotechnology-focused companies, on the other hand, cannot leave the field, but are unable to afford to provide the data on the safety of their products increasingly requested by their customers. There are some signs that companies unsure of how to deal with potential risks may be trying to sidestep the issue by simply not using the term "nanotechnology" in their product descriptions.

The Lux report notes that many environmental groups have advocated for increased funding for research on the environmental and safety implications of nanotechnology and several have called for temporary or permanent moratoria on nanotechnology products. The report also suggests that regulation by agencies such as EPA, FDA, the Occupational Safety and Health Administration, and the Consumer Product Safety Commission, is in the offing, but notes that the timing and substance of regulatory action remain uncertain. Many companies have been pressing these agencies to provide information about their plans in this area and to take actions that will reduce the uncertainty surrounding regulation of nanotechnology.

Due to the uncertainty of the current research and regulatory environments, the Lux report recommends that companies develop their own plans to address potential real and perceived risks of nanomaterials and products. The Lux report does not in-

⁷In addition to the three reports described in detail in this charter, Guy Carpenter & Company, Inc., a leading risk and reinsurance specialist and a part of the Marsh & McLennan Companies, Inc., published a report in August 2006 titled, "Nanotechnology: The Plastics of the 21st Century." The report provides businesses and risk managers with an overview of the field and some of the environmental issues that can be expected to arise relating to insurance and government regulation. In another important report issued just before the Science Committee's Nov. 2005 hearing, Innovest, an investment research firm that rates companies on their environmental management and performance, issued a report titled, "Nanotechnology" (October 2005), in which it introduced an investment index for investors. The report discusses the market viability of nano-products and materials in light of environmental and safety issues that could play a role in commercialization and in company performance. It also provides an overview of company best practices. The report distills a list of 300 public and private companies found in NanoInvestornews.com down to an index of 15 companies, and a watch list of an additional eight companies. Innovest is tracking the indexed companies and updates its findings for clients.

⁸Lux Research, "Taking Action," 2006.

⁹Lux Research, "A Prudent Approach to Nanotech Environmental, Health and Safety Risks." May, 2005.

clude any recommendations for the research or regulatory agencies of the Federal Government.

Wilson Center Inventory of Research on the Environmental and Safety Impacts of Nanotechnology

As was discussed at the Science Committee's last hearing on this topic, in 2005 the Wilson Center began assembling an inventory of ongoing research into the environmental and safety impacts of nanotechnology; the analysis of this inventory was released just after the hearing in November 2005.¹⁰ The inventory catalogs research funded by governments around the world as well as some research funded by industry and foundations. The primary purpose of the inventory is to facilitate strategic, coordinated and integrated research among the public and private sectors on research in this area. While the inventory is not complete, it includes all the available public information on federally-sponsored research.

The Wilson Center's initial analysis¹¹ of the inventory highlights two main points. The first is that significant gaps exist in the current portfolio of federally supported research projects. For example, the Wilson Center found few projects focused on controlling or preventing exposure to engineered nanomaterials and their release into the environment, as well as little research into the diseases and environmental impacts that may result from exposure. While there were many research projects studying the hazards of exposure to nanoparticles, most research focused on the lungs, with no projects focusing on the gastrointestinal tract. The Wilson Center's research needs report, described in the next section, suggests that these gaps in the research portfolio may reflect the absence of an overall federal strategy for conducting research on the environmental and safety impacts of nanotechnology.

The second main finding of the analysis is the inconsistency between the Wilson Center inventory and the federal budget supplement. The Wilson Center found \$31 million worth of research projects funded by the U.S. Government in 2005 that had some relevance to the potential environmental and safety risks of nanotechnology. However, only \$11 million of the \$31 million was going to projects that specifically focused on the environmental or safety implications of nanotechnology. In contrast, the FY07 NNI budget supplement states that, in FY05, the federal agencies in NNI spent \$35 million on research for which the primary purpose was understanding and addressing potential environmental and safety risks of nanotechnology. The Wilson Center inventory includes the available public information on federally sponsored research, and since the NNI has not developed its own detailed inventory of projects in this area, it is not currently possible to determine why these accountings differ.

Table 2. Comparison of NNI-reported funding for research on environmental and safety implications of nanotechnology and data on funding levels in that area gathered by the Wilson Center in 2005. (Dollars are in millions.)

Agency	NNI-Reported: Environment Health, and Safety Implications Research (FY05 Actual)	Wilson Center Reported: Risk-Related Research (all relevant research)	Wilson Center Reported: Risk-Related Research (highly relevant research)
NSF	20.9	19.0	2.5
DOD	1.0	1.1	1.1
DOE	0.5	0.3	-
DHHS (NIH)	2.7	3.0	3.0
DOC (NIST)	0.0	1.0	-
EPA	6.7	2.6	2.3
USDA (CSREES)	0.1	-	-
DHHS (NIOSH)	3.0	3.1	1.9
USDA/FS	-	0.5	-
TOTAL	34.8	30.6	10.8

¹⁰ The Wilson Center inventory continues to be updated; the most current version is available online at <http://www.nanotechproject.org/18>. Information from the inventory was included in the November 17, 2005 hearing record.

¹¹ This analysis was performed on the inventory as of November 23, 2005.

Wilson Center, "Nanotechnology: A Research Strategy for Addressing Risk"

In July 2006, Dr. Andrew Maynard, the Wilson Center's Chief Scientist, and a former NIOSH scientist, proposed a research strategy for "systematically exploring the potential risks of nanotechnology."¹² Based on the significant knowledge gaps identified in a variety of research needs reports from federal agencies, private groups, and international bodies; the Wilson Center's inventory of research in this area; his own experience in interagency activities while at NIOSH; and a risk-based framework that he developed, the report outlines the highest priority areas of research in which investment is needed between 2007 and 2009 to ensure the safety of technologies in use or close to commercialization and lay the groundwork for future research needs. The highest short-term priorities include identifying and measuring exposure and environmental releases, assessing toxicity, controlling releases, and developing best practices for worker safety, while longer-term needs include investment in areas such as predictive toxicology, the ability to predict the toxicological effects of nanomaterials.

The report also makes recommendations for changes in federal nanotechnology programs to ensure that the appropriate investments are made and the programs are carried out effectively. First, the report calls for the Federal Government to shift funding for research on environmental and safety impacts of nanotechnology to those federal agencies with clear mandates and expertise in risk-related research, including EPA, NIOSH, NIEHS, and NIST, and the analysis in the report suggests that these agencies will require a minimum of \$100 million over the next two years to carry out the needed research. The report also expresses concern that the current interagency process is insufficient and that gaps in the research portfolio are resulting from a bottom-up approach in which each agency develops its own research priorities. The report therefore recommends the establishment of a new interagency oversight group with the "authority to set and implement a strategic research agenda" and to assure adequate resources for those agencies carrying out the highest priority research.

The report also recommends that the Federal Government work closely with outside groups in executing research in this area. It says that mechanisms are needed to facilitate government-industry research partnerships and to enable international collaboration and information sharing. It cites the Health Effects Institute, an organization that has effectively addressed controversial air pollution research through joint government and private sector funding, as an excellent model for what is needed.¹³ It also calls for international cooperation to share research costs and exchange information.

The report also calls for a long-term research strategy to be developed and reviewed regularly by an organization such as the National Academies. This recommendation is consistent with the recommendation made by Dr. Richard Denison, of the environmental organization Environmental Defense, in his testimony before the committee at the November 17, 2005 hearing.

7. Witness Questions

Questions for Dr. Norris Alderson, Food and Drug Administration

In your testimony, please briefly describe the responsibilities and activities of the National Nanotechnology Environmental and Health Implications (NEHI) Working Group and address the following questions:

- What are the overall priorities for federally-supported research on the environmental and safety impacts of nanotechnology and how are these priorities determined? To what extent is the NEHI Working Group involved in setting or recommending funding levels for research in these areas? How are research roles allocated among the different agencies? How are ongoing research activities coordinated?
- When will the federal report that describes research needs for assessing and managing the potential risks of nanotechnology be completed and released? How is the NEHI Working Group incorporating information about risk and about the research needs of federal regulatory activities into the research needs document? How is input from groups outside of government, including industry, incorporated?

¹²Wilson Center, Project on Emerging Nanotechnologies, "Nanotechnology: A Research Strategy for Addressing Risk," July, 2006.

¹³The Health Effects Institute (HEI) is an independent, non-profit research organization, chartered in 1980, to provide high-quality, impartial, and relevant science on the health effects of air pollution. Typically, HEI receives half of its core funds from the EPA and half from the worldwide motor vehicle industry. <http://www.healtheffects.org>

- What topics will the report cover and what issues will remain to be addressed in the future? What will be the responsibilities and activities of the NEHI Working Group once the report is complete?

Questions for Dr. Arden Bement, National Science Foundation

In your testimony, please briefly describe NSF's current and proposed fiscal year 2007 programs and funding for research on possible environmental and safety risks associated with nanotechnology, and address the following questions:

- What are your agency's research priorities for studies of environmental and safety impacts of nanotechnology? How were these priorities determined, and what would cause them to change? To what extent is your research agenda specifically designed to inform potential regulation? How have you decided what portion of your nanotechnology funding to allocate to research in this area?
- In what specific ways has your agency's research agenda been shaped by interagency coordination? Are there areas of research you are conducting because they have not been taken up by other agencies or areas that you are forgoing because other agencies are taking on that research? Is there research being done because of the specific needs of regulatory agencies?

Questions for Dr. William Farland, Environmental Protection Agency

In your testimony, please briefly describe EPA's current and proposed fiscal year 2007 programs and funding for research on possible environmental and safety risks associated with nanotechnology and address the following questions:

- What are your agency's research priorities for studies of environmental and safety impacts of nanotechnology? How were these priorities determined, and what would cause them to change? To what extent is your research agenda specifically designed to inform potential regulation? How have you decided what portion of your research funding to allocate to nanotechnology-related projects?
- In what specific ways has your agency's research agenda been shaped by interagency coordination? Are there areas of research you are conducting because they have not been taken up by other agencies or areas that you are forgoing because other agencies are taking on that research? Is there research being done because of the specific needs of regulatory agencies?

Questions for Dr. Altaf (Tof) Carim, Department of Energy

In your testimony, please briefly describe the Department of Energy's current and proposed Fiscal Year 2007 (FY07) programs and funding for research on possible environmental and safety risks associated with nanotechnology and address the following questions:

- What are your agency's research priorities for studies of environmental and safety impacts of nanotechnology? How were these priorities determined, and what would cause them to change? To what extent is your research agenda specifically designed to inform potential regulation? How have you decided what portion of your nanotechnology funding to allocate to research in this area?
- In what specific ways has your agency's research agenda been shaped by interagency coordination? Are there areas of research you are conducting because they have not been taken up by other agencies or areas that you are forgoing because other agencies are taking on that research? Is there research being done because of the specific needs of regulatory agencies?

Questions for Dr. Andrew Maynard, Project on Emerging Nanotechnologies, Woodrow Wilson Center

In your testimony, please briefly describe the results of the Wilson Center's inventory of federal research on the environmental and safety impacts of nanotechnology and the report, "Nanotechnology: A Research Strategy for Addressing Risk?", and address the following questions:

- Are current federal and private research efforts adequate to address concerns about environmental and safety impacts of nanotechnology? Are there gaps in the portfolio of federal research currently underway; if so, in what areas?
- What should be the priority areas of research on environmental and safety impacts of nanotechnology? How should the responsibility for funding and

conducting this research be divided among the federal agencies, industry, and universities?

- What elements should the forthcoming report on research needs produced by the National Nanotechnology Environmental and Health Implications Working Group contain to adequately guide federal research investment in this area? What additional steps are needed to improve management and coordination of federal research on the environmental and safety impacts of nanotechnology?

Questions for Mr. Matthew Nordan, Lux Research

Please address the following questions in your testimony:

- What are the primary concerns about the environmental and safety impacts of nanotechnology based on the current understanding of nanotechnology?
- What impacts are environmental and safety concerns having on the development and commercialization of nanotechnology-related products and what impact might these concerns have in the future?
- What should be the priority areas of research on environmental and safety impacts of nanotechnology? How should the responsibility for funding and conducting this research be divided among the federal agencies, industry, and universities?
- Are current federal and private research efforts adequate to address concerns about environmental and safety impacts of nanotechnology? Are there gaps in the portfolio of federal research currently underway; if so, in what areas?
- What additional steps are needed to improve management and coordination of the Federal Government's research enterprise?

Appendix: Hearing Charter from November 17, 2005 Hearing on Environmental and Safety Impacts of Nanotechnology: What Research is Needed?

HEARING CHARTER

**COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES**

**Environmental and Safety
Impacts of Nanotechnology:
What Research Is Needed?**

THURSDAY, NOVEMBER 17, 2005
10:00 A.M.—12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

1. Purpose

On Thursday, November 17, 2005, the Committee on Science of the House of Representatives will hold a hearing to examine current concerns about environmental and safety impacts of nanotechnology and the status and adequacy of related research programs and plans. The Federal Government, industry and environmental groups all agree that relatively little is understood about the environmental and safety implications of nanotechnology and that greater knowledge is needed to enable a nanotechnology industry to develop and to protect the public. The hearing is designed to assess the current state of knowledge of, and the current research plans on the environmental and safety implications of nanotechnology.

2. Witnesses

Dr. Clayton Teague is the Director of the National Nanotechnology Coordination Office, the office that coordinates federal nanotechnology programs. The office is the staff arm of the Nanoscale Science, Engineering, and Technology Subcommittee of the National Science and Technology Council (NSTC). NSTC includes all federal research and development (R&D) agencies and is the primary coordination group for federal R&D policy.

Mr. Matthew M. Nordan is the Vice President of Research at Lux Research Inc., a nanotechnology research and advisory firm.

Dr. Krishna C. Doraiswamy is the Research Planning Manager at DuPont Central Research and Development, and is responsible for coordinating DuPont's nanotechnology efforts across the company's business units.

Mr. David Rejeski is the Director of the Project on Emerging Nanotechnologies at the Woodrow Wilson International Center for Scholars.

Dr. Richard Denison is a Senior Scientist at Environmental Defense.

3. Overarching Questions

- What impacts are environmental and safety concerns having on the development and commercialization of nanotechnology-related products and what impact might these concerns have in the future?
- What are the primary concerns about the environmental and safety impacts of nanotechnology based on the current understanding of nanotechnology?
- What should be the priority areas of research on environmental and safety impacts of nanotechnology? Who should fund and who should conduct that research?
- Are current federal and private research efforts adequate to address concerns about environmental and safety impacts of nanotechnology? If not, what additional steps are necessary?

4. Brief Overview

- Nanotechnology is expected to become a major engine of economic growth in the coming years. According to Lux Research,¹⁴ a private research firm that focuses on nanotechnology, in 2014 there could be \$2.6 trillion worth of products in the global marketplace which have incorporated nanotechnology—15 percent of manufacturing output. Lux also predicts that in 2014, 10 million manufacturing jobs worldwide—11 percent of total manufacturing jobs—will involve manufacturing these nanotechnology-enabled products.
- There is a growing concern in industry that the projected economic growth of nanotechnology could be undermined by real environmental and safety risks of nanotechnology or the public's perception that such risks exist.
- The small size, large surface area and unique behavioral characteristics of nanoparticles present distinctive challenges for those trying to assess whether these particles pose potential environmental risks. For example, nanoscale materials such as buckyballs, nano-sized clusters of carbon atoms, behave very differently than their chemically-equivalent cousin, pencil lead. There is an unusual level of agreement among researchers, and business and environmental organizations that basic scientific information needed to assess and protect against potential risks does not yet exist.
- In December 2003, the President signed the *21st Century National Nanotechnology Research and Development Act* (P.L. 108–153), which originated in the Science Committee. This Act provided a statutory framework for the interagency National Nanotechnology Initiative (NNI). Among other activities, the Act called for the NNI to ensure that research on environmental concerns is integrated with broader federal nanotechnology research and development (R&D) activities.
- Federal funding for the NNI has grown from \$464 million in fiscal year 2001 (FY01) to a requested \$1.1 billion in FY06. Of the requested FY06 level, the President's budget proposes that \$38.5 million (four percent of the overall program) be directed to research on environmental and safety implications of nanotechnology.

5. Background

The National Academy of Sciences describes nanotechnology as the “ability to manipulate and characterize matter at the level of single atoms and small groups of atoms.” An Academy report describes how “small numbers of atoms or molecules. . . often have properties (such as strength, electrical resistivity, electrical conductivity, and optical absorption) that are significantly different from the properties of the same matter at either the single-molecule scale or the bulk scale.”¹⁵

Nanotechnology is an enabling technology that will lead to “materials and systems with dramatic new properties relevant to virtually every sector of the economy, such as medicine, telecommunications, and computers, and to areas of national interest such as homeland security.”¹⁶ As an enabling technology, it is expected to be incorporated into existing products, resulting in new and improved versions of these products. Some nanotechnology-enabled products are already on the market, including stain-resistant, wrinkle-free pants, ultraviolet-light blocking sun screens, and scratch-free coatings for eyeglasses and windows. In the longer run, nanotechnology may produce revolutionary advances in a variety of industries, such as faster computers, lighter and stronger materials for aircraft, more effective and less invasive ways to find and treat cancer, and more efficient ways to store and transport electricity.

The projected economic growth of nanotechnology is staggering. In October 2004, Lux Research, a private research firm, released its most recent evaluation of the potential impact of nanotechnology. The analysis found that, in 2004, \$13 billion worth of products in the global marketplace incorporated nanotechnology. The report projected that, by 2014, this figure will rise to \$2.6 trillion—15 percent of manufacturing output in that year. The report also predicts that in 2014, ten million manufacturing jobs worldwide—11 percent of total manufacturing jobs—will involve manufacturing these nanotechnology-enabled products.¹⁷

¹⁴ Lux Research, “Sizing Nanotechnology's Value Chain,” October 2004.

¹⁵ *Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative*, National Research Council/National Academy of Sciences, 2002.

¹⁶ *Id.*

¹⁷ Lux Research, “Sizing Nanotechnology's Value Chain,” October 2004.

6. How Might Environmental and Safety Risks Affect the Commercialization of Nanotechnology?

Lux Research Report on Environmental and Safety Risks of Nanotechnology

In May, 2005, Lux Research published a comprehensive analysis of how environmental and safety risks could affect the commercialization of nanotechnology.¹⁸ While a limited number of studies have been done on specific environmental impacts, the report concludes that the few that have been done raise sufficient cause for concern. This leads to what the report calls a fundamental paradox facing companies developing nanotechnology: "They must plan for risks without knowing precisely what they are." The report then identifies two classes of risk that are expected to effect commercialization: "*real* risks that nanoparticles may be hazardous and *perceptual* risks that they pose a threat regardless of whether or not it is real." The report calculates that at least 25 percent of the \$8 trillion in total projected revenue from products incorporating nanotechnology between 2004 and 2014 could be affected by real risks and 38 percent could be affected by perceived risk."

The report describes that varying levels of risk are suspected for different types of nanomaterials and products and for different phases of a product's life cycle. For example, some nanoclay particles raise little initial concern because they would be locked up in composites to be used in automotive bodies. On the other hand, cadmium-selenide quantum dots that could be injected into the body for medical imaging tests are highly worrisome due to the toxicity of cadmium-selenide and the fact that they would be used within the human body.

Another factor that contributes to the potential risk of different nanotechnology-related products is the expected exposure of people and the environment over the product's life cycle.

The manufacturing phase is the first area of concern because workers potentially face repeated exposure to large amounts of nanomaterials.¹⁹ During product use, the actual risk will vary depending in part on whether the nanoparticles have been fixed permanently in a product, like within a memory chip in a computer, or are more bio-available, like in a sun screen where exposure may be more direct or may continue over a long period of time. Finally, the greatest uncertainties exist about the risks associated with the end of a product's life because it is difficult to predict what method of disposal, such as incineration or land disposal, will be used for a given material, and there has been little research on, for example, what will happen to nanomaterials within products stored in a landfill over 100 years.

The Lux Research report finds that nanotechnology also faces significant perceived risks. These risks are driven by people's general concerns about new technologies that they may be exposed to without being aware of it. However, public perceptions of nanotechnology are still up in the air and may be influenced by the press and non-governmental organizations. The report argues that, with a concerted effort to emphasize the benefits of nanotechnology, communicate honest assessments of toxicological effects, and engage all interested stakeholders from the outset, the public could be made comfortable with this new technology.

Woodrow Wilson International Center Study on Public Perceptions

A more in-depth survey of public perception of nanotechnology was recently completed by Woodrow Wilson Center's Project on Emerging Technologies.²⁰ The study found that the public currently has little knowledge about nanotechnology or about how risks from nanotechnology will be managed. This lack of information can lead to mistrust and suspicion. However, the study shows that when people learned more about nanotechnology and its promised benefits, approximately 80 percent were supportive or neutral about it. Once informed, people also expressed a strong preference for having more information made available to the public, having more testing done before products were introduced, and having an effective regulatory system. They do not trust voluntary approaches and tend to be suspicious of industry. The lesson, according to the report, is that there is still time to shape public perception and to

¹⁸ Lux Research, "A Prudent Approach to Nanotech Environmental, Health and Safety Risks." May 2005

¹⁹ Lux Research's findings on worker exposure are consistent with the concerns expressed in the recent report on the NNI by the President's Council of Advisors on Science and Technology. The report, *National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel*, is available online at http://www.nano.gov/FINAL_PCAST_NANO_REPORT.pdf.

²⁰ *Informed Public Perception of Nanotechnology and Trust in Government*, Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars is available online at http://www.pewtrusts.com/pdf/Nanotech_0905.pdf.

ensure that nanotechnology is developed in a way that provides the public with information it wants and establishes a reasonable regulatory framework.

7. Emerging Environmental and Safety Concerns

Initial research on the environmental impacts of nanotechnology has raised concerns. For example, early research on buckyballs (nano-sized clusters of 60 carbon atoms) suggests that they may accumulate in fish tissue. Although it may turn out that many, if not most, nanomaterials will be proven safe in and of themselves and within a wide variety of products, more research is needed before scientists can determine how they will interact with people and the environment in a variety of situations.

Nanotechnology's potential to affect many industries stem from that fact that many nanoscale materials behave differently than their macroscale counterparts. For example, nano-sized quantities of some electrical insulating materials become conductive, insoluble substances may become soluble, some metals become explosive, and materials may change color or become transparent. These novel features create tremendous opportunities for new and exciting applications, but also enable potentially troubling new ways for known materials to interact with the human body or be transported through the environment. It is difficult and would be misleading to extrapolate from current scientific knowledge on how materials behave in their macro-form to how they will behave in nano-form, and new techniques to assess toxicity, exposure, and ultimately public and environmental risks from these materials may be needed.

Widely Recognized Research and Development Needs

Businesses, non-governmental organizations, academic researchers, federal agencies, and voluntary standards organizations all have efforts underway to address concerns about the environmental and safety implications of nanotechnology. However, a number of organizations, including business associations and environmental groups, worry that environmental R&D is not keeping pace with the rapid commercialization and development of new nanotechnology-related products. There is widespread agreement on the following research and standards needs:

- Nanotechnology needs an accepted nomenclature. For example, "buckyballs" is the equivalent of a trade name; it does not convey critical information about the content, structure, or behavior of nanoparticles as traditional chemical nomenclature does for traditional chemicals. The lack of nomenclature creates a variety of problems. For example, it is difficult for researchers to know whether the nanomaterial they are working with is the same as that presented in other research papers. Similarly, it is difficult for a company to know whether it is buying the same nanomaterial from one company that it previously bought from another.
- Nanotechnology needs an agreed upon method for characterizing particles. Nanoparticles unique size enables unusual behavior. At these small sizes, particles can have different optical and electrical properties than larger particles of the same material. In addition, the large surface area of nanoparticles relative to their mass makes nanoparticles more reactive with their surroundings. Further complicating efforts to characterize nanomaterials is that small changes to some nanoparticles, such as altering the coatings of buckyballs, significantly modify the physical properties (and hence the potential toxicity) of the particles.
- A great deal more information is needed on the mechanisms of nanoparticle toxicity. Early studies suggest that a variety of nanoparticles damage cells through oxidative stress. (Oxidation is believed to be a common source of many diseases such as cancer.) A better understanding of the chemical reactions that nanoparticles provoke or take part in within living organisms will enable researchers to more effectively predict which nanomaterials are most likely to cause problems.
- Basic information on how nanomaterials enter and move through the human body are needed. Early studies point to wide variations in the toxicity of nanomaterials depending on the how exposure occurred—through the mouth, skin contact, inhalation, or intravenously. Particles in the range of 1–100 nanometers are small enough to pass through cell walls and through the blood-brain barrier, making them particularly mobile once they enter the body. There is also concern that some nanoparticles could lodge in the lungs and might be so small as to be overlooked by the body's defense mechanisms that would normally remove these invaders from the body.

- More research is needed on how and why some nanoparticles appear to behave one way as individual particles, but behave differently when they accumulate or agglomerate. One study of buckyballs, for example, found that while individual buckyballs are relatively insoluble, they have a tendency to aggregate, which makes them highly soluble and reactive with bacteria, raising concerns about their transport in watersheds and their impact on ecosystems.

According to a variety of experts, many of whom are familiar with the development of the largely mature databases available on the behavior and toxicity of various chemicals, development of a parallel collection of information on nanotechnology-related materials may take as long as 10–15 years.

Call for a Governmental Program on Environmental and Safety Implications of Nanotechnology

Recently, the American Chemistry Council and the environmental organization, Environmental Defense, agreed on a Joint Statement of Principles that should guide a governmental program for addressing the potential risks of nanoscale materials.²¹ They call for, among other things,

- “a significant increase in government investment in research on the health and environmental implications of nanotechnology,”
- “the timely and responsible development of regulation of nanomaterials in an open and transparent process,”
- “an international effort to standardize test protocols, hazard and exposure assessment approaches and nomenclature and terminology,”
- “appropriate protective measures while more is learned about potential human health or environmental hazards,” and
- a government assessment of “the appropriateness of or need for modification of existing regulatory frameworks.”

8. Federal Government Activities

The National Nanotechnology Initiative (NNI) is a multi-agency research and development (R&D) program begun in 2001 and formally authorized by Congress in 2003.²² Currently, 11 federal agencies have ongoing programs in nanotechnology R&D, while another 11 agencies participate in the coordination and planning work associated with the NNI. The primary goals of the NNI are to foster the development of nanotechnology and coordinate federal R&D activities.²³

Federal funding for the NNI has grown from \$464 million in FY01 to a requested \$1.1 billion in FY06. Of the requested FY06 level, the President’s budget proposes that \$38.5 million (four percent of the overall program) be directed to research on environmental, health, and safety implications of nanotechnology (see Table 1).²⁴

²¹Environmental Defense and American Chemistry Council Nanotechnology Panel, Joint Statement of Principles, Comments on EPA’s Notice of Public Meeting on Nanoscale Materials, June 23, 2005. The full statement is available online at <http://www.environmentaldefense.org/documents/4857-ACC-ED-nanotech.pdf>.

²²In 2003, the Science Committee wrote and held hearings on the *21st Century National Nanotechnology Research and Development Act*, which was signed into law on December 3, 2003. The Act authorizes \$3.7 billion over four years (FY05 to FY08) for five agencies (the National Science Foundation, the Department of Energy, the National Institute of Standards and Technology, the National Aeronautics and Space Administration, and the Environmental Protection Agency). The Act also: adds oversight mechanisms—an interagency committee, annual reports to congress, an advisory committee, and external reviews—to provide for planning, management, and coordination of the program; encourages partnerships between academia and industry; encourages expanded nanotechnology research and education and training programs; and emphasizes the importance of research into societal concerns related to nanotechnology to understand the impact of new products on health and the environment.

²³The goals of the NNI are to maintain a world-class research and development program; to facilitate technology transfer; to develop educational resources, a skilled workforce, and the infrastructure and tools to support the advancement of nanotechnology; and to support responsible development of nanotechnology.

²⁴There is of course additional federal funding being spent on fundamental nanotechnology R&D that has the potential to inform future studies on environmental and safety impacts, so the \$38.5 million may be a low estimate of the relevant research underway.

Table 1. NNI Proposed FY2006 Investments in environmental implications (\$ in millions)

Agency	Total Spending on Nanotechnology R&D	Environment, Health and Safety Implications R&D	Percent of Total Environment, Health and Safety Implications R&D
NSF	\$344	\$24.0	62.3
DOD	\$230	\$1.0	2.6
DOE	\$207	\$0.5	1.3
NASA	\$32	\$0.0	0.0
NIH	\$144	\$3.0	7.8
NIOSH	\$3	\$3.1	8.1
DOC	\$75	\$0.9	2.3
USDA	\$11	\$0.5	1.3
EPA	\$5	\$4.0	10.4
DOJ	\$2	\$1.5	3.9
DHS	\$1	\$0.0	0.0
Total	\$1054	\$38.5	100.0%

Source: NNI FY 06 Supplement Report: p. 36, 38.

To coordinate environmental and safety research on nanotechnology, the National Science and Technology Council organized in October 2003 the interagency Nanotechnology Environmental and Health Implications Working Group (NEHI WG), composed of agencies that support nanotechnology research as well as those with responsibilities for regulating nanotechnology-based products. NEHI WG is in the process of developing a framework for environmental R&D for nanotechnology that it expects to release in January 2006. To provide useful guidance to agencies, Congress, academic researchers, industry, environmental groups, and the public, the research framework will need to define the scale and scope of the needed research, set priorities for research areas, provide information that can affect agency-directed spending decisions, and be specific enough to serve as overall research strategy for federal and non-federal research efforts.

Currently, over 60 percent of the environmental research funding is provided by the National Science Foundation (NSF). In FY05 and FY06, NSF is putting a small amount of funding (approximately \$1 million each year) into a joint solicitation on investigating environmental and human health effects of manufactured nanomaterials with the Environmental Protection Agency, the National Institute for Occupational Safety and Health (NIOSH), and National Institute of Environmental Health Sciences (NIEHS). However, the majority of the NSF's funding in this area is distributed to projects proposed in response to general calls for nanotechnology-related research; projects are selected based on the quality and potential impact of the proposed research. It is not distributed based on the research needs of regulatory agencies such as EPA, OSHA or FDA. Currently NSF and the research community base their understanding of priorities in environmental research on a 2003 workshop "Nanotechnology Grand Challenge in the Environment,"²⁵ but the federal framework being developed by the NEHI WG should provide helpful, updated guidance for future research solicitations and proposals.

EPA's Office of Research and Development is the second largest sponsor of research on the environmental implications of nanotechnology, providing approximately 10 percent (\$4 million) of the federal investment. At the beginning of the NNI, EPA focused its research program on the development of innovative applications of nanotechnology designed to improve the environment, but in FY03, EPA began to shift its focus to research on the environmental implications of nanotechnology. In FY04 and FY05, EPA has increasingly tailored its competitive solicitations to attract research proposals in areas that will inform decisions to be made by the agency's regulatory programs. In January 2006, EPA is planning to re-

²⁵ "Nanotechnology Grand Challenge in the Environment: Research Planning Workshop Report," from the workshop held May 8-9, 2003, is available online at <http://es.epa.gov/ncer/publications/nano/nanotechnology4-20-04.pdf>.

lease an agency-wide nanotechnology framework that will describe both the potential regulatory issues facing the agency and the research needed to support decisions on those issues.

NIOSH sponsors eight percent (\$3 million) of research on environmental and safety implications of nanotechnology, and its activities are driven by the fact that minimal information is currently available on dominant exposure routes, potential exposure levels and material toxicity. NIOSH is attempting fill those gaps by building on its established research programs on ultra-fine particles (typically defined as particles smaller than 100 nanometers). The National Toxicology Program, an inter-agency collaboration between NIOSH and NIEHS, also supports a portfolio of projects studying the toxicity of several common nanomaterials, including quantum dots, buckyballs, and the titanium dioxide particles that have been used in cosmetics. NIOSH published a draft research strategy in late September 2005.

Private Sector Research

There is little information about how much individual companies are investing in research on the environmental and safety implications of nanotechnology. There are, however, a variety of activities underway in industry associations emphasizing the importance of research in this area. Members of the American Chemistry Council's ChemStar panel, for example, have committed to ensuring that the commercialization of nanomaterials proceeds in ways that protect workers, the public and the environment. Other elements of the chemical and semiconductor industries have formed the Consultive Boards for Advancing Nanotechnology, which has developed a list of key research and evaluation, identifying toxicity testing, measurement, and worker protection.

Potential Regulatory and Policy Issues.

Some companies, especially large firms that operate in many industry sectors, have significant experience dealing with environmental issues and risk management plans, are comfortable dealing with potential environmental and safety implications arising from nanotechnology. However, many companies that are involved with nanotechnology-related products are small, start-up companies or small laboratories with less experience in this area. According to the Lux Research report described above, some of these small enterprises do not carry out testing because they lack the resources to do so, while others do not do so because of fear they might learn something that could create legal liability or create barriers to commercializing their product.

At EPA, the regulatory program offices are trying to determine whether and to what degree existing regulatory programs can and should be applied to nanotechnology. For example, EPA is considering how the Toxic Substances Control Act (TSCA) will apply to nanotechnology, having recently approved the first nanotechnology under that statute. (See Appendix A for a recent Washington Post article discussing the issue). Enacted in 1976, TSCA authorizes EPA to regulate new and existing chemicals and provides EPA with an array of tools to require companies to test chemicals and adopt other safeguards. Decisions on conventional chemicals under TSCA are driven by a chemical's name, test data, and models of toxicity and exposure. Because much of this information does not yet exist for nanotechnology, EPA is having a difficult time deciding how best to proceed. The lack of information led to EPA's recent proposal to create a voluntary program under which companies would submit information that would help the agency learn about nanotechnology more quickly. EPA is now evaluating all of its water, air and land regulatory responsibilities to determine whether and how EPA should handle nanotechnology in these areas.

Other federal agencies with regulatory responsibilities, such as the Food and Drug Administration and the Occupational Safety and Health Administration, are also trying to determine how they will address environmental and safety concerns related to nanotechnology.

A number of observers, including the United Kingdom's Royal Society,²⁶ have suggested a precautionary approach to nanotechnology until more research has been completed. They urge caution especially regarding applications in which nanoparticles will be purposely released into environment. Examples of these so-called dispersive uses are nanomaterials used to clean contaminated groundwater

²⁶The United Kingdom's Royal Society and Royal Academy of Engineering's report "Nanoscience and Nanotechnologies: Opportunities and Uncertainties" was published in July 2004 and is available online at <http://www.nanotec.org.uk/finalReport.htm>

or those that when discarded enter the sewer system and thereby the Nation's waterways.

9. Witness Questions

The witnesses were asked to address the following questions in their testimony:

Questions for Dr. Clayton Teague

In your testimony, please briefly describe current federal efforts to address possible environmental and safety risks associated with nanotechnology and address the following questions:

- What impacts are environmental and safety concerns having on the development and commercialization of nanotechnology-related products and what impact might these concerns have in the future?
- What are the primary concerns about the environmental and safety impacts of nanotechnology based on the current understanding of nanotechnology?
- What should be the priority areas of research on environmental and safety impacts of nanotechnology? Who should fund and who should conduct that research?
- How much is the Federal Government spending for research on environmental and safety implications of nanotechnology? Which agencies have the lead? What additional steps are needed?

Questions for Mr. Matthew Nordan

In your testimony, please briefly describe the major findings of the Lux Research report on environmental and safety issues associated with nanotechnology and address the following questions:

- What impacts are environmental and safety concerns having on the development and commercialization of nanotechnology-related products and what impact might these concerns have in the future?
- What are the primary concerns about the environmental and safety impacts of nanotechnology based on the current understanding of nanotechnology?
- What should be the priority areas of research on environmental and safety impacts of nanotechnology? Who should fund and who should conduct that research?
- Are current federal and private research efforts adequate to address concerns about environmental and safety impacts of nanotechnology? If not, what additional steps are necessary?

Questions for Dr. Krishna Doraiswamy

In your testimony, please briefly describe what DuPont is doing to address possible environmental and safety risks associated with nanotechnology and answer the following questions:

- What impacts are environmental and safety concerns having on the development and commercialization of nanotechnology-related products and what impact might these concerns have in the future?
- What are the primary concerns about the environmental and safety impacts of nanotechnology based on the current understanding of nanotechnology?
- What should be the priority areas of research on environmental and safety impacts of nanotechnology? Who should fund and who should conduct that research?
- Are current federal and private research efforts adequate to address concerns about environmental and safety impacts of nanotechnology? If not, what additional steps are necessary?

Questions for Mr. David Rejeski

In your testimony, please briefly describe the major findings of the Wilson Center's recent study on public perceptions about nanotechnology and answer the following four questions:

- What impacts are environmental and safety concerns having on the development and commercialization of nanotechnology-related products and what impact might these concerns have in the future?
- What are the primary concerns about the environmental and safety impacts of nanotechnology based on the current understanding of nanotechnology?

- What should be the priority areas of research on environmental and safety impacts of nanotechnology? Who should fund and who should conduct that research?
- Are current federal and private research efforts adequate to address concerns about environmental and safety impacts of nanotechnology? If not, what additional steps are necessary?

Questions for Dr. Richard Denison

- What impacts are environmental and safety concerns having on the development and commercialization of nanotechnology-related products and what impact might these concerns have in the future?
- What are the primary concerns about the environmental and safety impacts of nanotechnology based on the current understanding of nanotechnology?
- What should be the priority areas of research on environmental and safety impacts of nanotechnology? Who should fund and who should conduct that research?
- Are current federal and private research efforts adequate to address concerns about environmental and safety impacts of nanotechnology? If not, what additional steps are necessary?

Appendix A

Nanotechnology's Big Question: Safety

Some Say Micromaterials Are Coming to Market Without Adequate Controls

THE WASHINGTON POST

OCTOBER 23, 2005, PAGE A11

BY JULIET EILPERIN, WASHINGTON POST STAFF WRITER

With little fanfare, the Environmental Protection Agency has for the first time ruled on a manufacturer's application to make a product composed of nanomaterials, the new and invisibly small particles that could transform the Nation's engineering, industrial and medical sectors.

The agency's decision to approve the company's plan comes amid an ongoing debate among government officials, industry representatives, academics and environmental advocates over how best to screen the potentially toxic materials. Just last week, a group of academics, industry scientists and federal researchers, working under the auspices of the nonprofit International Life Sciences Institute, outlined a set of principles for determining the human health effects of nanomaterial exposures.

By year-end, the EPA plans to release a proposal on how companies should report nanomaterial toxicity data to the government.

"Toxicity studies are meaningless unless you know what you're working with," said Andrew Maynard, who helped write the institute's report and serves as chief science adviser to the Project on Emerging Nanotechnologies at the Woodrow Wilson International Center for Scholars, a Washington-based think tank.

Because of their tiny size, nanomaterials have special properties that make them ideal for a range of commercial and medical uses, but researchers are still trying to determine how they might affect humans and animals. Gold, for example, may behave differently when introduced at nanoscale into the human body, where it is chemically inert in traditional applications.

The institute's report urged manufacturers and regulators to evaluate the properties of nanomaterials in laboratory tests, adding: "There is a strong likelihood that the biological activity of nanoparticles will depend on physiochemical parameters not routinely considered in toxicology studies."

The EPA decided last month to approve the "pre-manufacture" of carbon nanotubes, which are hollow tubes made of carbon atoms and potentially can be used in flat-screen televisions, clear coatings and fuel cells. The tubes, like other nanomaterials, are only a few ten-thousandths the diameter of a human hair.

Jim Willis, who directs the EPA's chemical control division in the Office of Pollution Prevention and Toxics, said he could not reveal the name of the company that received approval for the new technology or describe how that technology might be marketed. He added, however, that the EPA reserved the right to review the product again if the company ultimately decides to bring it to market.

Nanomaterials are already on the market in cosmetics, clothing and other products, but these items do not fall under the EPA's regulatory domain. EPA officials judge applications subject to the *Toxic Substances Control Act* (TOSCA), a law dating from the mid-1970s that applies to chemicals.

In a Wilson Center symposium last Thursday, Willis said "it is a challenge" to judge nanotechnology under existing federal rules.

"Clearly, [TOSCA] was not designed explicitly for nanoscale materials," he said, but he added that chemicals "have quite a number of parallels for nanoscale materials" and that "in the short-term, we are going to learn by doing."

Scientific studies also suggest nanoparticles can cause health problems and damage aquatic life. For instance, they lodge in the lungs and respiratory tract and cause inflammation, possibly at an even greater rate than asbestos and soot do.

"Nanoparticles are like the roach motel. The nanoparticles check in but they don't check out," said John Balbus, health program director for the advocacy group Environmental Defense. "Part of this is a societal balancing act. Are these things going to provide such incredible benefits that we're willing to take some of these risks?"

Nanomaterials have possible environmental advantages as well. For instance, they can absorb pollutants in water and break down some harmful chemicals much more quickly than other methods.

"Just because something's nano doesn't mean it's necessarily dangerous," said Kevin Ausman, Executive Director of Rice University's Center for Biological and En-

vironmental Nanotechnology. He added that when it comes to nanotechnology's toxic effects, "we're trying to get that data before there's a known problem, and not after there's a known problem."

Companies such as DuPont are pushing to establish nanotechnology safety standards as well, in part because they have seen how uncertainties surrounding innovations—such as genetically modified foods—have sparked a backlash among some consumers.

"The time is right for this kind of collaboration," said Terry Medley, DuPont's Global Director of corporate regulatory affairs. "There's a general interest on everyone's part to come together to decide what's appropriate for this technology."

Chairman BOEHLERT. I want to welcome everyone to this important hearing on a subject that has been a matter of continuing concern to this committee.

As our hearing last fall on this subject brought home, a great deal is at stake in setting a research agenda on the environmental and safety consequences of nanotechnology. I am still out of breath. The nanotechnology industry, which has enormous economic potential, will be stymied if the risks of nanotechnology are not clearly understood and addressed. And, of course, the potential danger to human beings and the environment is literally incalculable if we don't understand how nanotechnology can interact with our bodies and our world. That is why there is unusual agreement among every sector—business, government, environmental advocacy groups—that we need to get a handle on this issue. Our witnesses will underscore these basic points again today.

There is also broad agreement, I think, about what the government has to do to protect both the public and business. The government needs to establish and implement a clear, prioritized research agenda and fund it adequately. The problem is that we still haven't done that, and "time is a wasting."

The federal agencies have made some steps in the direction of setting an agenda, which, admittedly, is a difficult process. I am pleased that the long-delayed interagency report on research needs is finally being released at, and dare I say, because of, our hearing today. But as that document itself states, it is only a first step, and it doesn't fully set priorities, never mind assign them. So we are on the right path to dealing with the problem, but we are sauntering down it at a time when a sense of urgency is required.

The second problem, of course, is that environmental research on nanotechnology is grossly under-funded. Conservative estimates of what is needed are more than twice as much as we are spending today. This is "penny wise and pound foolish," to put it mildly, given what nanotechnology could contribute to our economy and what health problems from nanotechnology could detract from it.

So I hope that our discussion today can infuse everyone here, including the media and the public, with a sense of urgency about this problem. We need to come up with a mechanism in which priorities will be set for, assigned to, and actually carried out by the responsible federal agencies. Current coordinating mechanisms clearly are inadequate, and I hope we can have a good discussion today of what to do to replace that current mechanism.

I know that diversity is a source of strength in our research establishment, and I am not one who believes that duplication is always a bad thing. But we have to bring some order to this process or we are going to squander our chance to understand nanotechnology on a schedule that will help business and protect the public.

So I look forward to hearing from our witnesses today, and I can assure them we will be following up on this. At the very least, until the day I leave this chair in this institution Dec. 31, and hopefully long past that.

Let me just address a couple of protocol matters before I turn to Mr. Gordon.

First, I am going to try to keep witnesses and Members to their five minutes, because we have a huge panel and votes may occur as early as 11:30. Second, let me say that normally, we would have Dr. Bement testify first, as the highest-ranking official on the panel, but we wanted to hear first from the official who is chairing the interagency effort to get some perspective. Finally, I understand that Mr. Farland has announced his retirement, and I want to thank him for his years of helping this committee and for serving the public. That is something we both have announced: our retirement. We will go forth together.

With that, let me turn to Mr. Gordon.

[The prepared statement of Chairman Boehlert follows:]

PREPARED STATEMENT OF CHAIRMAN SHERWOOD L. BOEHLERT

I want to welcome everyone to this important hearing on a subject that has been a matter of continuing concern to this committee.

As our hearing last fall on this subject brought home, a great deal is at stake in setting a research agenda on the environmental and safety consequences of nanotechnology. The nanotechnology industry, which has enormous economic potential, will be stymied if the risks of nanotechnology are not clearly understood and addressed. And, of course, the potential danger to human beings and the environment is literally incalculable if we don't understand how nanotechnology can interact with our bodies and our world. That's why there's unusual agreement among every sector—business, government, environmental advocacy groups—that we need to get a handle on this issue. Our witnesses will underscore these basic points again today.

There's also broad agreement, I think, about what the government has to do to protect both the public and business. The government needs to establish and implement a clear, prioritized research agenda and fund it adequately. The problem is that we still haven't done that, and "time's a wasting."

The federal agencies have made some steps in the direction of setting an agenda, which, admittedly, is a difficult process. I'm pleased that the long-delayed interagency report on research needs is finally being released at—and dare I say, because of—our hearing today. But as that document itself states, it's only a first step, and it doesn't fully set priorities, never mind assign them. So we're on the right path to dealing with the problem, but we're sauntering down it at a time when a sense of urgency is required.

The second problem, of course, is that environmental research on nanotechnology is grossly underfunded. Conservative estimates of what's needed are more than twice as much as we're spending today. This is "penny wise and pound foolish," to put it mildly, given what nanotechnology could contribute to our economy and what health problems from nanotechnology could detract from it.

So I hope that our discussion today can infuse everyone here—including the media and the public—with a sense of urgency about this problem. We need to come up with a mechanism in which priorities will be set for, assigned to, and actually carried out by the responsible federal agencies. Current coordinating mechanisms clearly are inadequate, and I hope we can have a good discussion today of what to do instead.

I know that diversity is a source of strength in our research establishment, and I am not one who believes that duplication is always a bad thing. But we have to bring some order to this process or we're going to squander our chance to understand nanotechnology on a schedule that will help business and protect the public.

So I look forward to hearing from our witnesses today, and I assure them we will be following up on this at the very least until the day I leave office on Dec. 31, and hopefully long past that.

Let me just address a couple of protocol matters before I turn to Mr. Gordon. First, I'm going to try to keep witnesses and Members to their five minutes because we have a large panel and votes may occur as early as 11:30. Second, let me say that normally, we would have Dr. Bement testify first as the highest ranking official on the panel, but we wanted to hear first from the official who is chairing the interagency effort to get some perspective. Finally, I understand that Mr. Farland has announced his retirement, and I want to thank him for his years of helping this committee and serving the public.

Mr. Gordon.

Mr. GORDON. Thank you, Mr. Chairman.

As usual, I concur with your remarks, and let me assure you that that oversight will go beyond December 31 to honor you as well as to do our job here.

Let me recap.

This morning's hearing is a follow-up on our hearing of last November that addressed the health and environmental risks that may arise from applications of nanotechnology. That hearing clarified several important points and raised new issues. All the previous witnesses who represented government, industry, and non-government organizations stressed that nanotechnology will advance faster and receive public support if the environmental health and safety implications of the technology are understood.

To that end, all witnesses stressed the need for the interagency National Nanotechnology Initiative to include a prioritization and adequately funded component focused on environmental health and safety issues. The outside witnesses either recommended that NII—or rather NNI—increase funding for the EHS research or expressed frustration that they were unable to determine exactly what EHS research was being supported by NNI.

And finally, the Administration witness at the hearing told us an Interagency Working Group was developing a coordinated approach to nanotechnology research on EHS. This process would identify and prioritize research needs to assess the risks associated with engineering nanotechnology materials and be sufficiently detailed to guide researchers and research managers in making project-level decisions. That sounded like a good idea.

We were told the research plan would be available by the spring of 2006, but it has only just appeared, as a matter of fact, last night, I think, at six o'clock. And unfortunately, it is not the prioritized research plan we expected to see. This is the product that came last night at six o'clock, although we were promised it this spring, and I am very disappointed—I think it is a very juvenile piece of work, given the time that you have had to work on this. You did not get the job done. And in the back of it, it says, "Next steps." Well "next steps" seems to me like first steps. Next steps says "further prioritize research needs among those identified in this report." Well, this report is just an accumulation of things that need to be done. There is no prioritization. That is what you were supposed to be doing in this one: evaluate in greater detail the current NNI EHS research portfolios. You don't know what those portfolios are yet? I mean, what have you been doing since 2003? I mean, it seems to me there is just a lack of urgency. Materials are out on the market now. You know, it is just really hard to understand.

Mr. Chairman, I, frankly, do not understand the inability of the responsible agencies to produce their research plan with well defined priorities and resources requirements. It is the first step for developing proposed research programs in associated budgets for fiscal year 2008. It is now late in the budget planning cycle for fiscal year 2008. So what then will the agencies use to guide their selection of EHS research projects and determine their budget requirements?

In the absence of a prioritized EHS research plan, I see no way to initiate a carefully crafted set of research programs that are relevant to the needs of the companies that will be developing and using nanomaterials and to the needs of the agencies charged with oversight of EHS aspects of nanotechnology.

As we learned from the previous hearings, applications of nanomaterials are rapidly advancing. Consumer products employing nanomaterials are already on the market. The Wilson Center's Nanotechnology Project has identified at least 200 such products, many of which are actually designed to be ingested. Prudence suggests the need for urgency in having the science of health and environmental implications catch up to, or, even better, surpass the pace of commercialization.

But here we are today, nearly a year after our initial nanotechnology hearing on health and environmental risks, with little sign of forward progress in focusing the interagency research effort. I want to hear from our witnesses why progress has been so slow. Or if you are satisfied with this process and you think it is hunky-dory and we are just where we should be, I would like for you to tell us that. But if you are not satisfied, I would like for you to tell us why, and what we need to do from now.

We need to consider whether the interagency process under the NNI can be made to function to meet environmental health and safety needs. And if not, we must look for an alternative approach without further delay.

So, Mr. Chairman, this is a very important hearing, and I thank you for bringing us together for this.

[The prepared statement of Mr. Gordon follows:]

PREPARED STATEMENT OF REPRESENTATIVE BART GORDON

This morning's hearing is a follow-on to our hearing of last November that addressed the health and environmental risks that may arise from applications of nanotechnology. That hearing clarified several important points and raised new issues.

All the previous witnesses, who represented government, industry, and non-government organizations, stressed that nanotechnology will advance faster and receive public support if the environmental, health, and safety implications of the technology are understood.

To that end, all witnesses stressed the need for the interagency National Nanotechnology Initiative (NNI) to include a prioritized and adequately funded component focused on environmental, health, and safety issues.

The outside witnesses either recommended that the NNI increase funding for EHS research or expressed frustration that they were unable to determine exactly what EHS research was being supported by the NNI.

And finally, the Administration witness at the hearing told us an interagency working group was developing a coordinated approach to nanotechnology research on EHS. This process would identify and prioritize research needs to assess the risks associated with engineered nanomaterials and be sufficiently detailed to guide researchers and research managers in making project-level decisions.

We were told the research plan would be available by the spring of 2006, but it has only just appeared. And, unfortunately it is not the prioritized research plan we expected to see.

Mr. Chairman, I frankly do not understand the inability of the responsible agencies to produce a research plan with well defined priorities and resource requirements. It is the first step for developing proposed research programs and associated budgets for FY 2008.

It is now late in the budget planning cycle for FY 2008. What then will the agencies use to guide their selection of EHS research projects and to determine their budget requirements? In the absence of a prioritized EHS research plan, I see no way to initiate a carefully crafted set of research programs that are relevant to the

needs of the companies that will be developing and using nanomaterials and to the needs of the agencies charged with oversight of EHS aspects of nanotechnology.

As we learned from the previous hearing, applications of nanomaterials are rapidly advancing. Consumer products employing nanomaterials are now on the market. The Wilson Center's Nanotechnology Project has identified at least 200 such products, many of which are actually designed to be ingested.

Prudence suggests the need for urgency in having the science of health and environmental implications catch up to, or even better surpass, the pace of commercialization. But here we are today, nearly a year after our initial nanotechnology hearing on health and environmental risks with little sign of forward progress in focusing the interagency research effort. I want to hear from our witnesses why progress has been so slow.

We need to consider whether the interagency process under the NNI can be made to function to meet environmental, health and safety needs. And if not, we must look for an alternative approach without further delay.

Mr. Chairman, I believe that is the key issue the Committee should address relative to EHS research, and I look forward to the discussion today.

Chairman BOEHLERT. And I thank you for your opening statement.

Some of the sentiments you have expressed I share. I am not sure I—maybe it depends upon where you sit on how you would express it, but at least we are started, and we have got to get going. We have got to accelerate the pace. We have got to do a better job. I am not happy. You are not happy. And we have had good conversation, as is usual on this committee. This is a committee where we operate, I think, the way Congress should operate, and a lot of other committees. Guess what? We actually talk to each other. He has got a “D” after his name. I have got an “R” after my name. We know what is going to happen on November 7. It is going to be a big election. But we don't concentrate on politics. We concentrate on policy. And we are here collectively on this committee to try to encourage the best possible policy for the Nation, and we want to encourage all those present to work with us to accelerate the pace and do something quicker, better.

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good morning. I want to thank the witnesses for appearing before our committee to examine current concerns about environmental and safety impacts of nanotechnology and the status and adequacy of related research programs and plans.

Relatively little is understood about the environmental and safety implications of nanotechnology. The lack of knowledge about the effects of nanoparticles and the absence of established methods to assess their impacts on the environment and human health is troubling since nanomaterials are already on the market in cosmetics, clothing and other products. Further, there are no established scientific protocols for either safety or environmental compatibility testing for nanomaterials.

I am pleased we are having this hearing today because greater knowledge is needed to enable a nanotechnology industry to develop and to protect the public. Regulation for certain types or applications of nanomaterials could eventually be needed and Congress needs more information on the environmental and safety impacts of nanotechnology to better protect the public.

I look forward to hearing from the panel of witnesses.

[The prepared statement of Mr. Lipinski follows:]

PREPARED STATEMENT OF REPRESENTATIVE DANIEL LIPINSKI

Thank you, Mr. Chairman. I am pleased to be here today for this hearing on nanotechnology. Nanotechnology is one of the most promising technologies of our time and could revolutionize industries ranging from transportation to medicine, as well as have a huge impact on improving our national security.

Many universities and businesses are becoming invested in nanotechnology efforts in my home state of Illinois, which is one of the strongest states in nanotechnology research according to the *Small Times Magazine*. For example, Northwestern University, my alma mater, houses the Institute for Nanotechnology, which supports efforts in nanotechnology and facilitates collaboration in solving major problems in the field of nanotechnology. It includes the Center for Nanofabrication and Molecular Self-Assembly, a multi-million dollar research facility and one of the first federally funded centers of its kind. The Institute helps foster partnership to encourage researchers and entrepreneurs to become involved in this cutting edge technology, creating jobs and the potential for entirely new industries. In these times of increasing economic competitiveness, this new technology is extremely critical.

I would also like to recognize Jack Lavin, Director of the Illinois Department of Commerce and Economic Opportunity, for the work that he and the DCEO have done to make nanotechnology a strong presence in Illinois. They have worked to attract federal and private funds to the state to encourage the expansion of nanotechnology research and development and fully realize the vast economic benefits that our state will receive from current investment.

Yet there are numerous challenges still facing the development of nanotechnology, particularly regarding environmental and health safety. There is simply so much that we do not know about the ways that nanoparticles behave and how they interact with each other and other particles. The properties and behaviors can change dramatically when substances are reduced to such a small size. We need to at least better understand these changes. And this need is even more pressing considering that nanotechnology is already on the market in many products, from sun screen to stain resistant pants.

The Federal Government must promote research and education about the impacts of these emerging technologies, both to ensure that negative effects are minimized and to facilitate public acceptance of nanotechnology. Development of nanotechnology is surging ahead, with America as a leader in the international community, and I am pleased to see that. But we must make sure that proper health and environmental safeguards are in place, and government regulation may be necessary to ensure this safety.

On this note, I am disappointed with the just-released prioritized environmental, health, and safety research plan from the National Nanotechnology Initiative, six months late and lacking a clearly prioritized set of research objectives with specific agency responsibilities and costs. I look forward to receiving more information from the Administration on the "next steps" listed in this plan.

There is so much potential for our economy with nanotechnology that we must find a safe and comprehensive way to resolve these issues. Our economic future may depend on it.

Thank you, Mr. Chairman.

Chairman BOEHLERT. With that, let me introduce this panel.

Dr. Norris Alderson, Chair of Nanotechnology, Environmental Health Implications Working Group, Associate Commissioner for Science for Food and Drug Administration.

Dr. Arden Bement, Director, National Science Foundation.

Dr. William Farland, Deputy Assistant Administrator for Science, Office of Research and Development, U.S. Environmental Protection Agency. Thank you for your good work and your distinguished career.

Dr. Altaf Carim, Program Manager, Nanoscale Science and Electron Scattering Center, U.S. Department of Energy. Doctor.

Dr. Andrew Maynard, Chief Science Advisor, Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars. Dr. Maynard.

And Mr. Matthew Nordan, President, Director of Research, Lux Research, Inc. Mr. Nordan, thank you very much.

And thank all of you for being resources for this committee, for helping provide a tutorial for us, because you know a hell of a lot more about this than we do. We are trying to learn, but we want to work together, and I always appreciate it and I am very gratified

when I look down at the list of witnesses and see people of your caliber, your experience, your commitment.

So with that, let us go.

Dr. Alderson, you are first up.

**STATEMENT OF DR. NORRIS E. ALDERSON, CHAIR,
NANOTECHNOLOGY, ENVIRONMENTAL, AND HEALTH IMPLI-
CATIONS WORKING GROUP; ASSOCIATE COMMISSIONER
FOR SCIENCE, FOOD AND DRUG ADMINISTRATION**

Dr. ALDERSON. Good morning, Mr. Chairman, and Members of the Committee. Thank you for the opportunity to speak with you today about nanotechnology programs and the work of the Nanotechnology Environmental and Health Implications Working Group, or the NEHI Working Group.

I am Dr. Norris Alderson, Associate Commissioner for Science, at the Food and Drug Administration. As FDA's Associate Commissioner for Science, I am responsible for the management of the Office of Women's Health, the Office of Orphan Products Development and the Good Clinical Practices Staff. I am also responsible for coordination of science issues across the Agency, the oversight of FDA-sponsored clinical trials and standards coordination.

In addition to serving as Associate Commissioner for Science at FDA, I am also chair of the NEHI Working Group.

I have been with the NEHI Working Group since it was established by the Nanoscale Science, Engineering, and Technology, NSET, Subcommittee in 2003.

The purpose of the NEHI Working Group is to provide for the exchange of information among agencies that support nanotechnology research and those responsible for regulation and guidelines related to nanoproducts, products that contain engineered nanoscale materials to facilitate the identification, prioritization, and implementation of research and other activities required for the responsible research and development, utilization, and oversight of nanotechnology, including our research methods of life cycle analysis, and promote communication of information related to research on environmental and health implications of nanotechnology to other government agencies and non-government organizations.

One of the key objectives of the NEHI Working Group is to exchange information on the issues raised within the participating regulatory agencies by advances in nanotechnology. The NEHI Working Group assists in the development of information and strategies as a basis for the drafting by the regulatory agencies of guidance toward safe handling and use of nanoproducts by researchers, workers, and consumers. Further, the group is working to support development of nanotechnology standards, including nomenclature and terminology, by consensus-based standards organizations.

In pursuit of these aforementioned objectives, activities of the NEHI Working Group over the past two years include, and I just want to mention a few because of the time:

First, communication by participating regulatory agencies concerning their respective statutory authorities for regulating nanoproducts, and their approaches for carrying out these authorities. We encouraged all of the participating regulatory agencies to

develop a position statement of how they are addressing nanotechnology. This resulted in all of the agencies developing a website on their positions. We developed a preliminary “risk assessment influence diagram” that was ultimately published as a peer-reviewed publication. We have had discussions with various relevant standards bodies regarding nomenclature and terminology. And we have compiled the inputs from participating agencies on their perceived needs for EHS research and information and development of a draft document drawn from this compilation and inputs from industry. This draft document is now a final document, and it is a product of these activities that is in a report entitled “Environmental Health and Safety Research Needs for Engineered Nanoscale Materials.” I have the report, Mr. Chairman, and would like to submit a copy for the record. (*See Appendix 2: Additional Materials for the Record.*)

Chairman BOEHLERT. Without objection, so ordered.

Dr. ALDERSON. The primary purpose of this document is to identify for the Federal Government the EHS research and information needs related to understanding and management of potential risks of engineered nanoscale materials that may be used in commercial or consumer products, medical treatments, environmental applications, research, or elsewhere. In addition, industry producers and users of engineered nanoscale materials may use this document to inform their own research, risk assessment, and risk management activities.

The report is the first step in addressing the research needed to support informed risk assessment and risk management of nanomaterials. The document represents over a year of intensive work by the participating agencies.

In addition to gathering input from its members for the purposes of this report, the NEHI Working Group has considered a number of public documents, and those are included in the report. These are both domestic and international documents. These ideas were then grouped into five categories, which you will see in the report.

Research on nanoscale materials is supported by each agency respectively, based on its primary scientific mission. For example, the NIH supports a broad spectrum of biological nanoscale research ranging from basic science to clinical and translational investigations and clinical trials. The National Science Foundation supports basic research on engineered nanoscale materials and cells.

Chairman BOEHLERT. Excuse me, Mr. Alderson, could you somewhat wrap up? We are going to try to stick to the—here is what—

Dr. ALDERSON. Right.

Chairman BOEHLERT.—we are going to do. We are going to try to stick to the five minutes for everybody else. We are giving you a little leeway, because you are the Chair of the panel. But from my experience, I know when Administration witnesses come up, they tell us what they are doing right. We understand what you are doing right, but there are a lot of things that we are not happy with. And we know what the charge is, but we are not pleased with the implementation plan. So if you could, wrap it up, and then we could get to the other witnesses. And I am going to try to keep the other witnesses to the five minutes so we really can engage.

Dr. ALDERSON. Will do.

Chairman BOEHLERT. Thank you, sir.

Dr. ALDERSON. With the completion of the report released today, issues that remain to be addressed in the future include a step-wise process of determining priorities. Under the guidance of NSET, I expect the NEHI Working Group to play an active role in all of the "next steps" mentioned above, although the Working Group will serve only in an advisory capacity with respect to assisting agencies in setting their respective research priorities.

Thank you again for the opportunity to testify, Mr. Chairman. I appreciate the Committee's continued interest in nanotechnology, and I would be happy to answer any questions you may have.

[The prepared statement of Dr. Alderson follows:]

PREPARED STATEMENT OF NORRIS E. ALDERSON

INTRODUCTION

Mr. Chairman and Members of the Committee, thank you for the opportunity to speak with you today about nanotechnology programs and the work of the Nanotechnology Environmental and Health Implications (NEHI) Working Group. I am Dr. Norris Alderson, Associate Commissioner for Science, at the Food and Drug Administration (FDA or the Agency). As FDA's Associate Commissioner for Science, I am responsible for the management of the Office of Women's Health, the Office of Orphan Products Development, the Good Clinical Practices Staff, coordination of science issues across the Agency, and oversight of FDA-sponsored clinical studies and standards coordination.

OVERVIEW

Nanotechnology is expected to contribute to scientific advances in medicine, energy, electronics, materials, and other areas. Many of the benefits of nanotechnology arise from the fact that nanomaterials exhibit properties and behavior different from those of materials at larger scales. These unique properties that enable new benefits, however, also could lead to nanomaterial-specific human health and environmental risks.

That a new technology could offer both benefits and, at the same time, potential risk, is not unique to nanotechnology. Other common examples are electricity, household cleaning supplies, gasoline, and medical X-rays. Learning more about risks of technologies provides information for their successful management and the realization of their benefits.

NANOTECHNOLOGY ENVIRONMENTAL AND HEALTH IMPLICATIONS (NEHI) WORKING GROUP

I have been involved in the Nanotechnology Environmental and Health Implications (NEHI) Working Group since its inception. The Nanoscale Science, Engineering, and Technology (NSET) Subcommittee established the Working Group informally in late 2003 and formally chartered it in 2005.

The purpose of the NEHI Working Group is to provide for exchange of information among agencies that support nanotechnology research and those responsible for regulation and guidelines related to nanoproducts (containing engineered nanoscale materials); facilitate the identification, prioritization, and implementation of research and other activities required for the responsible research and development, utilization, and oversight of nanotechnology, including research methods of life-cycle analysis; and promote communication of information related to research on environmental and health implications of nanotechnology to other government agencies and non-government organizations.

One of the key objectives of the NEHI Working Group is to exchange information on the issues raised within the participating regulatory agencies by advances in nanotechnology. The NEHI Working Group assists in the development of information and strategies as a basis for the drafting by the regulatory agencies of guidance toward safe handling and use of nanoproducts by researchers, workers, and consumers. Further, the group is working to support development of nanotechnology standards, including nomenclature and terminology, by consensus-based standards organizations.

In pursuit of these aforementioned objectives, activities of the NEHI Working Group over the past two years include:

- communication by participating regulatory agencies concerning their respective statutory authorities for regulating nanoproducts, and their approaches for carrying out those authorities;
- encouraging all the participating regulatory agencies to develop a position statement on how they are addressing nanotechnology (an effort that has resulted in the establishment of a nanotechnology web site at most of the participating regulatory agencies);
- development of a preliminary “risk assessment influence diagram” to help guide the NEHI Working Group’s approach to thinking about potential risks from nanoproducts and services (this effort led to a peer-reviewed scientific publication);
- discussion with various relevant standards bodies regarding nomenclature and standards development for nanotechnology that will affect both regulators and researchers; and
- compiling the inputs from participating agencies on their perceived needs for Environmental, Health, and Safety (EHS) research and information and development of a draft document drawn from this compilation and inputs from industry and other similar documents from other countries and organizations.

A product of these activities is a report titled *Environmental, Health, and Safety Research Needs for Engineered Nanoscale Materials*.

THE NEHI WORKING GROUP REPORT

The primary purpose of this document is to identify for the Federal Government the EHS research and information needs related to understanding and management of potential risks of engineered nanoscale materials that may be used in commercial or consumer products, medical treatments, environmental applications, research, or elsewhere. In addition, industry producers and users of engineered nanoscale materials may use this document to inform their own research, risk assessment, and risk management activities.

The report is the first step in addressing the research needed to support informed risk assessment and risk management of nanomaterials. The document represents over a year of intensive work by the participating agencies.

In addition to gathering input from its members for the purposes of this report, the NEHI Working Group has considered a number of public documents on the subject of EHS research while drafting this report. Included were documents from the chemical industry, the Environmental Protection Agency (EPA), the National Institute for Occupational Safety and Health (NIOSH), the Royal Society/Royal Academy of Engineering in the United Kingdom, and the Scientific Committee on Emerging and New Identified Health Risks/European Commission.

Once the research needs were identified, they were grouped into five areas:

1. Instrumentation, metrology, and analytical methods
2. Nanomaterials and human health
3. Nanomaterials and the environment
4. Health and environmental surveillance
5. Risk management methods

Research on nanoscale materials is supported by each agency, respectively, based on its primary scientific mission. The National Institutes of Health (NIH) supports a broad spectrum of biological nanoscale research ranging from basic science to clinical and translational investigations and clinical trials; the National Science Foundation (NSF) supports basic research on interactions between engineered nanoscale materials and cells. The EPA looks at broader implications for both human health and the environment including how nanomaterials will potentially affect whole ecosystems containing many different organisms. In some cases, such as the EPA–NSF–NIOSH–National Institute of Environmental Health Sciences joint interagency solicitation on environmental implications of nanotechnology, agencies conduct joint review of proposals, and then allocate the top rated proposals among themselves according to their respective missions and program emphases.

The NEHI Working Group Report supports NSET’s mandate to coordinate federal nanoscale research activities. The document will serve as a uniform guide for all federal agencies in developing their plans to support environmental, health, and safety research on the implications of nanoscale materials.

NEXT STEPS

With the completion of the report released today, issues that remain to be addressed in the future include:

- Further prioritize research needs. Priorities will be evaluated based primarily on the principles outlined in the document. Other factors that will be considered include the time frame for developing the information—because certain studies are inherently lengthy—and the availability of research tools.
- Evaluate in greater detail the current National Nanotechnology Initiative (NNI) EHS research portfolio.
- Perform a “gap analysis” of the NNI EHS research compared to the prioritized needs.
- Coordinate and facilitate among the NNI agencies research programs to address priorities. Agencies will work individually and jointly, where possible, to address research needs.
- Establish a process for periodically reviewing progress and for updating the research needs and priorities. Such a review must take into consideration advances made by entities other than U.S. Government-funded bodies, such as advances by the private sector and foreign governments.

CONCLUSION

I expect the NEHI Working Group to play an active role in all of the “next steps” mentioned above; although, the Working Group will serve only in an advisory capacity with respect to assisting agencies in setting their respective research priorities. Thank you again for the opportunity to testify today, Mr. Chairman. I appreciate the Committee’s continued interest in nanotechnology, and I am happy to answer any questions you may have.

BIOGRAPHY FOR NORRIS E. ALDERSON

Associate Commissioner for Science, U.S. Food and Drug Administration (FDA). Dr. Alderson began his career in FDA in 1971 following a BS degree from the University of Tennessee and MS and Ph.D. degrees and post-doctoral work at the University of Kentucky. The majority of his FDA career has been in the Center for Veterinary Medicine, holding a number of management positions, culminating in the position of Director, Office of Research. In 2001, he became Acting Senior Advisor for Science, and Acting Director, Office of Science Coordination and Communication. In 2002, he was appointed Senior Associate Commissioner for Science, and Director, Office of Science and Health Coordination. The title was later changed to Associate Commissioner for Science. In his current position, he is responsible for coordination of science issues across the agency, the Office of Women’s Health, Office of Orphan Products Development, the Good Clinical Practices Staff, oversight of FDA sponsored clinical studies, and standards coordination.

Chairman BOEHLERT. Thanks very much. And incidentally, this committee has been privileged to have—to be familiar with all of you, because you have been before us. So—and I can say this without any fear of contradiction, that we know you individually and your careers, and we have high regard for you. And—but we are frustrated. I know how difficult it is to get interagency panels to act, and I know every single one of you have very demanding schedules. And this isn’t the only item on your agenda. But I hope you take from this hearing the feeling that both of us, all of us on this committee, would like it to be a little bit higher on your respective agendas, a little bit higher priority so that we can get beyond the preliminary stages. And I am being kind when I say, “Well, this is an important first step,” but we should be a couple of steps ahead.

Dr. Bement.

STATEMENT OF DR. ARDEN L. BEMENT, JR., DIRECTOR, NATIONAL SCIENCE FOUNDATION

Dr. BEMENT. Chairman Boehlert, Ranking Member Gordon, and distinguished Members of the Committee, I am pleased to be with

you once again to speak on behalf of the National Science Foundation.

However, before I begin my formal remarks today, Mr. Chairman, I want to extend a very warm personal note of appreciation for your support of NSF. Throughout the years, your leadership has been of immeasurable value to the science and engineering community. I know the work that you have done here will continue to strengthen this nation for years to come.

Chairman BOEHLERT. Thank you very much, sir.

Dr. BEMENT. Nowhere is that impact more evident than in the emerging field of nanotechnology. The amazing advances we have seen in this new frontier are, in no small part, due to your leadership in Congress on this issue. Your tremendous help in pushing the Administration's American Competitiveness Initiative will provide even more opportunities for discovery.

Mr. Chairman, with your help, NSF not only provides leadership for the National Nanotechnology Initiative, we also provide the lion's share, 72 percent, of the NNI's \$82 million research investments into the societal dimensions of nanotechnology. NSF also provides nearly 60 percent of the total NNI Environmental Health and Safety funding. These investments are critical, because we cannot effectively and safely exploit nanotechnology's fast potential without also understanding its societal implications.

NSF research in this area is categorized into three main groups: environmental health and safety; education; and ethical, legal, and social issues.

Of our investment, nearly half goes to fundamental research on the environmental health and safety aspects of nanomaterials. This also includes studying risk assessment. This research covers all the possible sources of nanoparticles: those created through manufacturing, those produced as a byproduct of other processes, and those existing naturally in the environment.

NSF research also investigates how nanoparticles behave in a variety of settings: in the laboratory, in water, in the air, and in the workplace. We also study their non-clinical biological implications, such as the development of new instrumentation to measure toxicity.

Funding a research agenda for these important areas is challenging, but managed in a variety of coordinated activities. NSF contributes and coordinates its NNI research and education activities through the Nanoscale Science, Engineering, and Technology Subcommittee, or NSET, of the National Science and Technology Council. Our activities are well integrated in the NSTC through periodic meetings, strategic and annual planning processes, co-sponsoring and co-funding events of program solicitations, all in the framework of NSET and the National Nanotechnology Coordination Office.

NSF is also part of NSET's subcommittees, namely Nanotechnology Environmental and Health Implications Working Group, or NEHI. This group provides regular interactions with other agencies that support research in regulatory activities.

In the recent past, we have coordinated grantees meetings with the Environmental Protection Agency, the National Institute of Environmental and Health Sciences, the National Institute for Occu-

pational Safety and Health, and other agencies. These meetings help ensure open lines of communication, cross-fertilization of ideas, funding of complementary projects, and leveraging.

NSF also sets internal annual priorities for its nanoscale science and engineering research. Input for these priorities come from the NSF's Nanoscale Science and Engineering Working Group, the NNI Strategic Plan, the National Academies, other national, international, and industry perspectives as well as from grass roots sources, such as the general public and your grantees meetings, and other non-governmental sources.

The NSF, according to its mission, conducts fundamental environmental health and safety research. This fundamental research complements the more directed approach of regulatory agencies in improving our understanding of the behavior of nanoparticles in the environment and their implications for human health and the ecology.

NSF's fundamental research also complements the toxicity studies conducted by the National Institutes of Health and regulatory activities of the EPA, the Food and Drug Administration, and NIOSH.

Mr. Chairman, NSF works closely with the regulatory agencies by offering our unique expertise and strength in fundamental research. This research will add to the overall body of knowledge on nanotechnology, provide the future workforce, and will prove essential to the regulatory mission agencies' abilities to develop science-based standards.

Mr. Chairman, I hope that this brief overview conveys to you NSF's continued commitment to advance science and technology in the national interest. I appreciate you and your Committee's longstanding support of NSF, and I will be pleased to answer any questions you may have.

[The prepared statement of Dr. Bement follows:]

PREPARED STATEMENT OF ARDEN L. BEMENT, JR.

Fundamental Nanotechnology Research: The Key to Finding the Promise and Minimizing the Peril

Chairman Boehlert, Ranking Member Gordon, and distinguished Members of the Committee, I am delighted to be with you once again to speak on behalf of the National Science Foundation. NSF is an extraordinary agency, with an equally extraordinary mission of enabling discovery, supporting education, and driving innovation—all in service to society and the Nation.

The past several months have been particularly exciting for the NSF and the U.S. research community. As you are well aware, the National Science Foundation is an integral part of the President's American Competitiveness Initiative (ACI). The President's request for an eight percent increase at NSF this year represents the first step in the Administration's commitment to doubling the budgets of the ACI research agencies over the next 10 years.

The ACI encompasses investments across NSF's research and education portfolio. NSF's investments in discovery, learning, and innovation have a longstanding and proven track record of boosting the Nation's economic vitality and competitive strength. This level of commitment is recognition of the urgent and ongoing need to invest in our nation's future through fundamental research and innovation.

Frontier research is NSF's unique task in pursuing the Administration's research priorities within the larger federal research and development effort. Over the years, NSF has advanced the frontier with support for pioneering research that has spawned new concepts and even new disciplines. NSF provides strong support in fundamental research for activities coordinated by the National Science and Technology Council (NSTC), including our role as a lead federal agency in the multi-agency National Nanotechnology Initiative (NNI).

But before I begin, let me thank this committee for its historic and ongoing support of NSF. I also want to extend special thanks—on behalf of everyone associated with the National Science Foundation—to Representative Boehlert for his many years of leadership as Chairman of the House Science Committee. The science and engineering community appreciates all that you have done as a champion for our nation’s quest for knowledge.

Nanotechnology—First Steps and Demand for Fundamental Principles

Ten years ago, predicting the state of nanotechnology research today would have been a fruitless gesture. In the 1990s, NSF and other research entities around the globe were just beginning to apply nanoscale concepts to the frontiers of science and engineering.

Though some visionary researchers certainly recognized the vast potential of skillful atomic and molecular manipulation, no one could have predicted the enormous impact of these early steps into a new realm of discovery. One reason for this lack of prescience is our limited understanding of the physical principles that come into play on the nanoscale.

The research community’s first vision for nanotechnology was based on our understanding of the macro world, where the same laws and physical properties of our everyday experience hold sway, regardless of size or scale. We now know that this simplistic view was woefully inaccurate. The world of nanotechnology—it turns out—is an often topsy-turvy world where familiar physical properties disappear and new capabilities emerge.

Consider something with which we are all familiar—ordinary gold. Whether in a ring, shielding sensitive electronics in space, or kept as a trusted investment for a rainy day, gold behaves in the same predictable ways. It has a certain color, luster, hardness, and melting point. This is true for an ounce or a metric ton. But something remarkable happens when we study the vanishingly small bits of gold called nanodots. On the nanoscale, gold no longer behaves the same as it does in our day-to-day lives. Its color changes to a striking red (as ancient stained-glass artists learned), and it’s no longer the inert metal used in home and biological appliances. Rather, under certain circumstances, gold nanoparticles may be very reactive, may penetrate the blood/brain barrier, or may enter into cells.

So we have to ask ourselves: as the NSF funds fundamental nanoscale research, how should we address the societal issues associated with the development and use of nanotechnology, and in particular engineered nanoscale materials.

Societal Dimensions

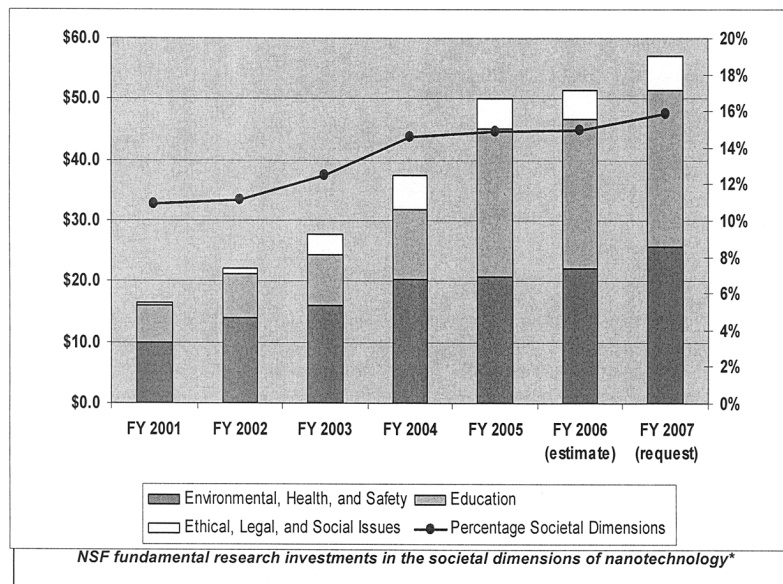
We typically refer to the impact of nanotechnology on the environment, humans, cultures, and societal relationships as the “societal dimensions” of nanotechnology. NSF characterizes research in this area into three main groups:

- Environment, Health, and Safety
- Education, and
- Ethical, Legal, and other Social Issues.

Each pillar of this triumvirate is indispensable, and removing one would weaken the stability of our efforts to effectively and safely exploit nanotechnology’s vast potential, which is why NSF’s support of fundamental research is so critical. Of the total 2007 NSF Request within the National Nanotechnology Initiative of \$373.2 million, \$59 million—or 16 percent—is directed toward societal dimensions.¹ This is a \$7.5 million (15 percent) increase over the FY 2006 estimated funding of \$51.5 million.

¹ NSTC/NSET, July 2006

* FY 2001–2004 data retrospectively collected based upon FY 2005 OMB guidance.



Because of NSF's critical impact on building a fundamental body of knowledge, specialized facilities, and qualified people, NSF funds a large fraction of the overall National Nanotechnology Initiative (NNI) investment in Societal Dimensions: \$59 million of \$82.1 million in the FY 2007 Request, and \$51.5 million of \$71.7 million in the FY 2006 estimate.

NSF dedicates about seven percent of its NNI budget to projects that focus primarily on fundamental aspects of environmental, health, and safety implications and applications of nanomaterials, and basic research that assesses the risk of these implications. This comes to \$25.7 million or 6.9 percent of the total FY 2007 NNI/NSF Request, or \$3.6 million over the FY 2006 estimate.

Setting a Research Agenda

NSF sets annual priorities for nanoscale science and engineering research. Input for these priorities comes from the NSF's Nanoscale Science and Engineering Working Group; the NNI strategic plan; other national, international, and industry perspectives; as well as from grassroots sources such as the general public, annual grantees meetings, and other non-governmental sources.

Another important input in developing the NSF's NNI-related research and education activities is through participation in the Nanoscale Science, Engineering and Technology Subcommittee (NSET) of the National Science and Technology Council (NSTC) Committee on Technology. NSF participates in all NNI workshops, research directions and planning meetings, and is coordinating its programs with the work done by other agencies in the general context of R&D, infrastructure, and education needs. NSF is also part of the NSET Subcommittee's Nanotechnology Environmental and Health Implications Working Group (NEHI), through which it has systematic interactions with other agencies supporting research and regulatory activities. NSF also has co-organized grantees meetings with the Environmental Protection Agency (EPA), the National Institute for Occupational Safety and Health (NIOSH), and other agencies to ensure open lines of communication, cross-fertilization of ideas, funding of complementary projects, and leveraging. Since FY 2001, the results from these meetings, and nanoscale science and engineering awards and solicitations, have been placed on NSF's dedicated nanotechnology web site: www.nsf.gov/nano.

NSF also receives input from industry on the impact of this research agenda, ensuring that it is both deep and broad, and one that will serve the fundamental research needs of the entire community.

NSF Focus on Environmental, Health, and Safety Research

As stated earlier, NSF—through its proven system of merit review—seeks to advance the central body of knowledge on nanotechnology and corresponding infrastructure by support for fundamental research, not including clinical testing, and other activities that address broad societal dimensions. We do not fund product development or late-stage innovation: the research necessary to move a product into a commercial market.

NSF research addresses a variety of nanoparticles and nanostructured materials in different environmental settings (air, water, soil, biosystems, and working environment), as well as the non-clinical biological implications. These topics are supported through programs in all the NSF research directorates.

There are several priority areas for environmental, health, and safety research at NSF. These key EHS priority research areas are:

- new measurement methods and instrumentation for nanoparticle characterization and nanotoxicity,
- transport phenomena of nanoscale aerosols and colloids, interaction of nanomaterials with cells and living tissues,
- safety in nanomanufacturing, physico-chemical-biological processes of nanostructures dispersed in the environment,
- separation of nanoparticles from fluids,
- development of user facilities, and
- educational programs supporting EHS issues.

For example, the NSF is funding research on the safety of manufacturing nanoparticles through four Nanoscale Science and Engineering Centers (NSECs) and one Network:

- The NSEC at Rice University in Houston is investigating the evolution of manufacturing nanoparticles in the wet environment;
- The NSEC at Northeastern University in Boston is looking into occupational safety during nanomanufacturing;
- The University of Pennsylvania's NSEC is exploring the complex behavior and interactions between nanomaterials and cells; and,
- The NSEC at University of Wisconsin, Madison, is looking broadly at the effects of nanostructured polymers on Environmental Health and Safety.
- The National Nanotechnology Infrastructure Network is also exploring societal dimensions through nanoparticle characterization centers at the University of Minnesota and Arizona State University.

Additionally, about twenty interdisciplinary research teams (NIRTs) were funded in the EHS area since FY 2001.² Research through these teams has covered such diverse topics as:

- Theoretical and experimental methods of describing the formation and transformation of carbon nanoparticles in the atmosphere.
- The effect on human cells of exposure to single-wall carbon nanotubes. Research at the Houston Advanced Research Center has indicated that these nanotubes have less toxicity than carbon black and silica. However, research results on toxicity depend on many factors and more knowledge is needed before a final conclusion can be reached.
- NSF also is looking into the robust large-scale manufacturing of nanoparticles and their toxicology. This project will involve an academic-government-industrial partnership, encompassing chemistry, chemical and mechanical engineering, and medicine. Extensive tests will be performed on toxicology. Mechanisms of particle/cell interactions will also be evaluated, and the potential adverse and beneficial effects will be determined.
- An NSF-supported Nanoscale Interdisciplinary Research team is investigating ceramic membranes for filtration of nanoparticles, which is relevant in control technology for manufacturing processes involving aqueous nanoparticles.
- An NSF-supported Nanoscale Interdisciplinary Research team is developing solvent-free techniques, using supercritical carbon dioxide, for the de-agglomeration of nanoparticles. This will enable environmentally benign manufacturing of high-surface-area nanostructured composites.

²NSF 2001–2006

In addition to the Center and NIRT awards, single investigator and small group awards provides creative ideas and innovation across all directorates in NSF. Several examples are:

- Several NSF awardees are developing instrumentation for monitoring nanoparticles which could be useful for ensuring the proper operation of control technology in factories. Examples include instrumentation for:
 - in-situ, real-time, high-resolution measurements of nanoparticle size distributions
 - chemical composition of nanoscale aerosols
 - size-resolved measurements of surface tension, critical supersaturation, and chemical composition of nanoscale cloud condensation nuclei, which will help elucidate the role of organic materials in environment
- Laser Doppler Velocimetry (LDV) in synchronous AC electric and acoustic fields, to determine the size and charge of nanoparticles. These technologies could also be used to monitor nanoparticle emissions in the environment, providing critical information for the design and implementation of mitigation strategies where needed.
- An NSF Nanoscale Exploratory Research project is developing risk scenarios for the full life-cycles of three types of nanoparticles currently manufactured in multi-ton quantities: endohedral metallo-fullerenes, titania nanoparticles, and carbon nanotubes. The project's broad interdisciplinary approach, including toxicity studies, life-cycle analysis, hierarchical holographic modeling, and assessment of the existing regulatory framework, will serve as a model for identifying environmental impacts and risks of nanomaterials.

Since FY 2002, NSF has had a Nanotechnology Undergraduate Education program. The program is currently sponsoring an effort to introduce research-based environmental nanotechnology experiences into the undergraduate curricula. Research-based hands-on laboratory modules will introduce students to the effects of nanomaterials on the environment and the potential use of nanomaterials for removal of environmental pollutants.

We also support fundamental research on decision making, risk, and uncertainty as part of our Human and Social Dynamics portfolio. This research will yield insight into decision-making processes, loss and mitigation models, and risk perception that are widely applicable to managing the risks and general governance associated with emerging technologies including nanotechnology.

NSF has also released a number of solicitations that deal directly with the societal impacts of nanotechnology. These include an NSF-wide solicitation in FY 2001 to FY 2005 that had two major research and education themes: nanoscale processes in the environment, and societal implications of nanotechnology. There also was a solicitation in FY 2006 and FY 2007 on active nanostructures and nano-devices.

Research to Enable Risk Assessment and Risk Management

What sort of research is necessary to enable sound risk assessment and risk management of nanotechnology? And what is the role of NSF in supporting that research? NSF's unique expertise and strength of its human and administrative resources is in fundamental research. This research will add to the overall body of knowledge on nanotechnology, will prove essential to the regulatory mission agencies' abilities to develop science-based standards, and complements the more applied approach of EPA, toxicity studies by the National Institutes of Health, and regulatory activities by the Food and Drug Administration and NIOSH.

By creating the strong foundation of fundamental research, NSF catalyses the development of trained researchers, the future workforce, and the laboratory infrastructure that is needed for the mission specific research and development in the regulatory agencies.

As with any new technology, the benefits and risks of nanotechnology need to be evaluated from the beginning; nanotechnology has been exemplary in this regard. But research to understand the benefits and risks cannot advance without the combination of fundamental research, domain specific research, and technology and product specific research. This is where a balanced approach ensures the best results. Without these three components, the successful long-term commercialization of new products is at risk.

This foundation for commercialization is of great concern to industry, and NSF activity integrates their input and concerns into its research agenda. NSF receives input from industry through the Collaborative Boards for Advancing

Nanotechnology, which was established by NNI with the electronic industry, the chemical industry, and other businesses and organizations.

NSF, therefore, does have an important role to play in enabling the acceptance of nanotechnology-based goods in the marketplace. Primarily, this is through fundamental research and the development of the necessary infrastructure—education, physical infrastructure for nanomaterials research, and more comprehensive topics such as nomenclature, metrology, and patent-evaluation framework. NSF also develops the institutional capability for R&D, production, information dissemination, safe use and regulations, and commercialization of nanotechnology. Above all, NSF supports the long-term R&D for new generations of nanoproducts. NSF research is most effective when targeted at long-term results and broad impacts that cut across the entire research landscape.

The Public and Nanotechnology

NSF supports a host of education-related activities to communicate the state and future direction of nanotechnology research. This includes developing materials for schools, curriculum development for nanoscience and engineering, development of new teaching tools, and K–12 and public outreach. Three networks for nanotechnology education and societal dimensions with national outreach have been established:

- The Nanotechnology Center for Learning and Teaching, with the main node at the Northwestern University, will reach one million students in high school and undergraduate education in all 50 states in the next five years;
- The Nanoscale Informal Science Education, focused at the Museum of Science in Boston will address innovative science learning approaches, supplement K–12 education, and engage adult audiences; and
- The Network for Nanotechnology in Society will address both short-term and long-term societal implications of nanotechnology, as well as public engagement.

The success of these efforts, however, hinges on a firm foundation of research across all areas and considering all implications. That outcome can only be achieved with the fundamental, broad-based research supported by NSF.

Conclusion

For many years, NSF has used the slogan “Where Discoveries Begin” to welcome people to our web site. That phrase, however, did not come from a focus group or a marketing guru: it came from our mission—our mission of research and discovery. The same is true for nanotechnology. NSF is where the discoveries begin.

Mr. Chairman, I hope that this brief overview conveys to you NSF’s continued commitment to advance science and technology in the national interest. If there is one thing that I would want to leave you with is that the vital, critical, and highly visible regulatory decisions that will need to be made will be based on the equally vital, critical, yet—by and large—unseen fundamental research that is NSF’s hallmark.

I appreciate your—and your committee’s—longstanding support of NSF. I would be pleased to answer any questions that you may have.

Thank you.

BIOGRAPHY FOR ARDEN L. BEMENT, JR.

Arden L. Bement, Jr., became Director of the National Science Foundation on November 24, 2004. He had been Acting Director since February 22, 2004.

He joined NSF from the National Institute of Standards and Technology, where he had been director since Dec. 7, 2001. Prior to his appointment as NIST director, Bement served as the David A. Ross Distinguished Professor of Nuclear Engineering and head of the School of Nuclear Engineering at Purdue University. He has held appointments at Purdue University in the schools of Nuclear Engineering, Materials Engineering, and Electrical and Computer Engineering, as well as a courtesy appointment in the Krannert School of Management. He was director of the Midwest Superconductivity Consortium and the Consortium for the Intelligent Management of the Electrical Power Grid.

Bement served as a member of the U.S. National Science Board from 1989 to 1995. The board guides NSF activities and also serves as a policy advisory body to the President and Congress. As NSF director, Bement will now serve as an ex officio member of the NSB.

He also chaired the Commission for Engineering and Technical Studies and the National Materials Advisory Board of the National Research Council; was a member

of the Space Station Utilization Advisory Subcommittee and the Commercialization and Technology Advisory Committee for NASA; and consulted for the Department of Energy's Argonne National Laboratory and the Idaho National Engineering and Environmental Laboratory.

Bement joined the Purdue faculty in 1992 after a 39-year career in industry, government, and academia. These positions included: Vice President of Technical Resources and of Science and Technology for TRW Inc. (1980–1992); Deputy Under Secretary of Defense for Research and Engineering (1979–1980); Director, Office of Materials Science, DARPA (1976–1979); Professor of nuclear materials, MIT (1970–1976); Manager, Fuels and Materials Department and the Metallurgy Research Department, Battelle Northwest Laboratories (1965–1970); and Senior Research Associate, General Electric Co. (1954–1965).

He has been a director of Keithley Instruments Inc. and the Lord Corp. and was a member of the Science and Technology Advisory Committee for the Howmet Corp. (a division of ALCOA).

Bement holds an Engineer of Metallurgy degree from the Colorado School of Mines, a Master's degree in metallurgical engineering from the University of Idaho, a doctorate degree in metallurgical engineering from the University of Michigan, an honorary doctorate degree in engineering from Cleveland State University, and an honorary doctorate degree in science from Case Western Reserve University. He is a member of the U.S. National Academy of Engineering.

Chairman BOEHLERT. Thank you very much, Dr. Bement.

You know, you are only 20 seconds over, but since you had that nice preamble, I allowed that.

Dr. Farland.

And incidentally, I apologize to no one. I am an unabashed cheerleader for the National Science Foundation. It does marvelous work.

Thank you.

STATEMENT OF DR. WILLIAM H. FARLAND, DEPUTY ASSISTANT ADMINISTRATOR FOR SCIENCE, OFFICE OF RESEARCH AND DEVELOPMENT, U.S. ENVIRONMENTAL PROTECTION AGENCY

Dr. FARLAND. Thank you, Mr. Chairman and Members of the Committee, for the invitation to appear here today and provide testimony on behalf of the Environmental Protection Agency. Mr. Chairman, thank you for your kind words regarding my career.

I am Dr. William Farland, Deputy Assistant Administrator for Science for the Office of Research and Development. EPA has been and will continue to be a leader in promoting development of environmental applications. EPA understands the potential implications of nanotechnology and vigorously pursues collaborations with United States and international scientists and policy makers. My submitted testimony describes our research needs in this area and how EPA is going about meeting these needs.

EPA recognizes that nanotechnology has the potential to improve the environment, both through direct applications to detect, prevent, and remove pollutants as well as through design of cleaner industrial processes and creation of environmentally-friendly products.

However, some of the same unique properties that make manufactured nanoparticles beneficial also raise questions about the impacts of nanoparticles on human health and the environment. The evaluation of potential nanoparticle toxicity is complex, possibly being regulated by a variety of physical chemical properties, such as size and shape, as well as surface properties, such as charge area reactivity, coating type, and others.

As products made from nanoparticles become more numerous, the potential for release of nano-sized particles into the environment may also increase. The EPA, under its various statutes, has an obligation to ensure that potential environmental risks are adequately understood and managed. Potential environmental risks are dealt with as we review information on nanomaterials to assess and understand these risks and take control measures, as needed. For example, EPA is reviewing pre-manufacture notifications on nanomaterials that have been received under Section 5 of the Toxic Substances Control Act. It is important that throughout our evaluation of nanotechnology, decision making be informed by the best available scientific information.

I mentioned that EPA has been a leader in research on the application and implications of nanotechnology in the environment. EPA began funding research on nanotechnology under its Science To Achieve Results, or STAR program, in 2001. Some 36 grants totaling nearly \$12 million have been funded since that time to identify beneficial environmental applications, addressing prevention, sensors, treatment, and remediation.

In addition, through its Small Business Innovation Research, or SBIR program, EPA has supported projects addressing nanotechnology applications. Beginning in 2003, EPA turned its focus to the potential environmental implications of nanotechnology and has now funded an additional 30 implications projects totaling approximately \$10.4 million under the STAR program. This research is addressing exposure, fate and transport of nanomaterials in the environment, and potential human and environmental toxicity. We partnered with the National Science Foundation, National Institute of Environmental Health Sciences, NIOSH, and have funded additional projects under these solicitations with their help. Currently EPA and the three partner agencies are reviewing the proposals from the latest joint solicitation to make new funding decisions.

While some EPA research needs are shared by other federal agencies, EPA has particular needs to support its statutory mandates. To that end, EPA has set research priorities that reflect these program needs. EPA plans to issue the final version of its nanotechnology white paper in the near future. This paper was released in December of 2005 as the review draft that describes EPA nanotechnology research needs. The needed research is in the following broad areas: chemical identification and characterization, environmental fate, environmental detection and analysis, potential releases to the environment and human exposures, and human health effects, as well as ecological effects.

Based on the President's fiscal year 2000 budget request, \$8.6 million will go toward nanotechnology research. The EPA is developing a nanotechnology research framework for fiscal years 2007 through 2012 that is problem-driven, focusing on addressing the agency's programmatic needs. EPA will conduct research to understand whether nanoparticles in particular, and those with the greatest potential to be released into the environment or trigger a hazard concern, pose significant risks to human health or ecosystems by looking at the life cycle of nanoparticles. We are also working with our federal partners to conduct research to identify

approaches for detecting and measuring nanoparticles in the environment and looking at pollution prevention and enhancing manufacturing processes.

Based on these kinds of recommendations, we will be able to continue our collaborative efforts in these research areas into the near future, and we look forward to these types of activities. As members of the National Science and Technology Council's Nanoscale Science, Engineering, and Technology Subcommittee, which manages the NNI, EPA plays a leadership role in the coordination of federal activities concerning nanotechnology and the environment, and we look forward to continuing these kinds of efforts as we move toward the future.

Chairman BOEHLERT. Thank you, Doctor.

Dr. FARLAND. Thank you, Mr. Chairman.

[The prepared statement of Dr. Farland follows:]

PREPARED STATEMENT OF WILLIAM H. FARLAND

Introduction

Thank you, Mr. Chairman and Members of the Committee for the invitation to appear here today and provide testimony on nanotechnology research at the Environmental Protection Agency (EPA). I am William Farland, Deputy Assistant Administrator for Science for the Office of Research and Development. EPA is a leader in promoting research to develop environmental applications and understand potential implications of nanotechnology, and vigorously pursues collaborations with U.S. and international scientists and policy-makers. My purpose today is to describe our research needs in this area, and how EPA is going about meeting these needs.

EPA recognizes that nanotechnology has the potential to improve the environment, both through direct applications to detect, prevent, and remove pollutants, as well as by using nanotechnology to design cleaner industrial processes and create environmentally friendly products. However, some of the same unique properties that make manufactured nanoparticles (which in the remainder of this testimony I refer to simply as "nanoparticles," recognizing that our focus is on particles intentionally manufactured at the nanoscale) beneficial also raise questions about the impacts of nanoparticles on human health and the environment. The evaluation of potential nanoparticle toxicity is complex, possibly being regulated by a variety of physicochemical properties such as size and shape, as well as surface properties such as charge, area, reactivity, and coating type on the particle. As products made from nanoparticles become more numerous, the potential for release of nano-size particles into the environment may also increase. The EPA, under its various statutes, has an obligation to ensure that potential environmental risks are adequately understood and managed. Certain EPA programs are already reviewing information on nanomaterials to assess and understand risks and take control measures as needed. For example, EPA is reviewing pre-manufacture notifications on nanomaterials that have been received under Section 5 of the *Toxic Substances Control Act*. It is important that throughout our evaluation of nanotechnology, decision-making be informed by the best available scientific information.

EPA began funding research on nanotechnology under its Science to Achieve Results (STAR) program in 2001. Some 36 grants totaling nearly \$12 million have been funded since that time to identify beneficial environmental applications, addressing prevention, sensors, treatment, and remediation of conventional pollutants using nanotechnology. In addition, through its Small Business Innovation Research program EPA has supported projects addressing nanotechnology applications.

Beginning in 2003, EPA turned its focus to the potential environmental implications of nanotechnology and has now funded an additional 30 implications projects totaling approximately \$10.4 million under the STAR program. This research is addressing potential human and environmental toxicity, exposure, and fate and transport of nanoparticles in the environment. EPA has partnered with the National Science Foundation, National Institute for Environmental Health Sciences (NIEHS), and National Institute for Occupational Safety and Health (NIOSH), which have funded additional projects under these solicitations. Currently, EPA and the three partner agencies are reviewing the proposals from the latest joint solicitation to make new funding decisions.

Research Needs

While some of EPA's research needs are shared by other federal agencies, EPA has particular needs to support its statutory mandates. To that end, EPA must set research priorities that reflect these program needs. EPA plans to issue its *Nanotechnology White Paper*, released in December 2005 as a review draft that describes EPA's nanotechnology research needs. This research is in the following broad areas: chemical identification and characterization, environmental fate, environmental detection and analysis, potential releases to the environment and human exposures, human health effects assessment, ecological effects assessment, and environmental applications.

Chemical Identification and Characterization

A number of properties will need to be considered in order to characterize nanoparticles for the purposes of evaluating hazard and assessing risk. Terminology and nomenclature also need to be standardized. EPA is participating in deliberations with the American National Standards Institute, the American Society for Testing and Materials, and the International Organization for Standardization regarding the development of terminology and chemical nomenclature for nano-sized substances, and will also continue with its own nomenclature discussions with the Chemical Abstracts Service.

Potential Releases and Human Exposures

Workers may be exposed to particles during the production and use of materials made from nanoparticles, and the general population may be exposed to releases to the environment during these materials' production or use in the workplace, during the use of commercially available products containing nanoparticles, and during disposal and recycling stages. Workers who manufacture materials made from nanoparticles may be exposed to higher levels of nanoparticles than the general population, and therefore may need additional personal protective equipment. Research is needed to better understand these exposures.

Environmental Detection and Analysis

The challenge in detecting nanoparticles in the environment is not only their extremely small size but also because the metric of importance is unknown. Consequently we are currently unsure of what to measure and detect. The chemical properties of particles at the nanometer size may require new analytical and detection techniques. To that end, we need to assess available detection methods and technologies for nanoparticles in environmental media, and to develop a set of standard methods for the sampling and analysis of nanoparticles of interest in various environmental media.

Environmental Fate

As more products are developed using nanoparticles, there is increased potential for releases of nanoparticles into the environment. Particles may be released to the environment during their manufacture and processing, or as they break down during use, disposal, or recycling. We need to understand what happens to these particles as they are released into and move through the air, soil, and water.

Human Health Effects

Very little data exist on the toxicity, hazardous properties, translocation, and ultimate fate of nanoparticles in humans. We need to understand whether adverse health effects may result from exposure to nanoparticles or their byproducts, by local toxic effects at the site of initial deposition as well as by systemic toxic responses. Toxicological assessment of manufactured nanoparticles will require information on the routes (inhalation, oral, dermal) that carry the greatest potential for exposure to nanoparticles.

Ecological Effects

Research is needed on the potential exposure and effects of nanoparticles on invertebrates, fish, and wildlife. Furthermore, dispersion of nanoparticles in the environment may result in novel byproducts or degradates that also may pose hazards. We need to understand the behavior of nanomaterials in aquatic and terrestrial environments, and nanoparticles' potential acute and chronic toxic effects. To do this, we need to develop and validate analytical methodologies for measuring nanoscale substances (both parent materials and metabolites/complexes) in the environment.

Environmental Applications

Nanotechnology can help create materials and products that will not only directly advance our ability to detect, monitor, and clean-up environmental contaminants,

but also help us avoid creating pollution in the first place. By using less materials and energy throughout a product's lifecycle—such as by using highly reactive nanoparticles as more-efficient catalysts—nanotechnology may contribute to reducing pollution and energy consumption. Research is needed to advance the use of nanotechnology to enhance environmental protection.

EPA Research

Based on the fiscal year 2007 President's budget request of \$8.6 million, EPA is developing a nanotechnology research framework for fiscal years 2007–2012 that is problem-driven, focusing on addressing the Agency's programmatic needs. EPA will conduct research to understand whether nanoparticles, in particular those with the greatest potential to be released into the environment and/or trigger a hazard concern, pose significant risks to human health or ecosystems, by looking at the life cycle of nanoparticles. Also, EPA will conduct research to identify approaches for detecting and measuring nanoparticles in the environment, and for using nanotechnology for pollution prevention and enhancing manufacturing processes, as well as to facilitate the development of nanotechnology-based materials in an environmentally benign manner.

This research program will be based on the recommendations from the *EPA Nanotechnology White Paper*, which was developed by a cross-agency committee working under the auspices of our Science Policy Council. Our research will be guided by the information needed to conduct assessments of risk to humans and the environment. We are uniquely positioned to lead in the ecosystem and exposure areas, due to our existing expertise in these areas. Also, because of expertise in areas such as fine particulate toxicology, we plan to engage in a limited amount of human health effects research. However, we also will look to partnerships and collaboration with other agencies to fill our research needs. For example, we are currently working with NIEHS to ensure that human toxicity research is conducted that is relevant and timely for environmental decision-making.

Because the President's budget request proposes to significantly increase EPA's nanotechnology research budget in 2007, I believe the Agency is well positioned to examine the potential human health and ecological risks from nanoparticles.

Collaboration

To meet the research needs outlined here, we need a collaborative approach that will energize the research community, public and private. EPA scientists are leaders in explaining how we can use nanotechnology to improve our environment and how we can improve our understanding of any potential adverse effects resulting from the production, use, disposal and recycling of materials that contain nanoparticles. We intend to continue these efforts and to increase direct collaborations on the research discussed above.

As a member of the National Science and Technology Council's Nanoscale Science, Engineering and Technology Subcommittee, which manages the National Nanotechnology Initiative, EPA plays a leadership role in the coordination of federal activities concerning nanotechnology and the environment. The Agency is also a pivotal member of the Subcommittee's Nanotechnology Environmental and Health Implications (NEHI) working group, whose membership includes, among others, EPA, Food and Drug Administration, Consumer Products Safety Commission, NIOSH, Department of Defense, Department of Energy, and NIH. The NEHI has prepared a research needs document, in the development of which EPA has played a central role, that complements our white paper.

EPA is also engaged in international collaboration. For example, EPA is part of the Organization for Economic Cooperation and Development effort to address the topic of the implications of manufactured nanomaterials among its members under the auspices of the Joint Meeting of the Chemicals Committee and Working Party on Chemicals, Pesticides and Biotechnology.

Conclusion

EPA recognizes the potential of nanotechnology to clean up the environment, prevent pollution, and contribute to the sustainable use of resources. EPA is also committed to improving our understanding of the properties of nanoparticles, the behavior of nanoparticles in the environment, and the potential for unintended consequences for humans and the environment from exposure to nanoparticles. The Agency will continue to play a domestic and international leadership role to better understand the environmental issues surrounding this and other emerging technologies. Mr. Chairman, I would like to thank you and the Committee for inviting EPA to participate in this hearing and for giving us this opportunity to describe our nanotechnology research program. I would be happy to answer any questions that you may have.

Chairman BOEHLERT. Thank you, Dr. Farland.
Dr. Carim.

STATEMENT OF DR. ALTAF H. (TOF) CARIM, PROGRAM MANAGER, NANOSCALE SCIENCE AND ELECTRON SCATTERING CENTER, U.S. DEPARTMENT OF ENERGY

Dr. CARIM. I am sorry. I thought it was on already.

Mr. Chairman and Members of the Committee, good morning, and thank you for the opportunity to speak with you today about nanotechnology programs at the Department of Energy. My name is Altaf Carim, and I manage major nanoscience user facilities and coordinate nanoscience activities in the Office of Science at DOE. The longstanding support of this committee for scientific research and development, including that carried out within the Office of Science, is deeply appreciated and Mr. Chairman, I also want to add thanks for your longstanding leadership in this area.

Nanoscale science and technology is, of course, a key area among those encompassed by the American Competitiveness Initiative. Collectively, these efforts do constitute vital investments that are essential to maintaining the U.S. leadership in innovation and its associated economic benefits.

The mission of DOE's Office of Science is "to deliver the remarkable discoveries and scientific tools that transform our understanding of energy and matter and advance the national, economic, and energy security of the U.S." To address this mission, the Office of Science includes key portfolio components in two types of activities: fundamental research in support of long-term energy security and discovery science that enables the DOE missions, and forefront scientific user facilities for the Nation which provide the infrastructure for world leadership in science. Accordingly, our nanotechnology activities include both support of basic research at universities and National Laboratories, and the development and operation of major facilities for nanoscale research.

Nanotechnology research programs at DOE are part of the broad portfolio of programs in the Office of Science, and are supported through submissions to our core research program, the equivalent of a broad agency announcement, as well as through a variety of other occasional solicitations. Only a few such solicitations have concentrated specifically on nanotechnology. The Office of Science also has a small program that supports research on the ethical, legal, and societal issues in two primary areas: biotechnology and nanotechnology. Broadly, decisions on research programs are made through peer review and merit evaluation and through program managers' judgments on portfolio balance. The determination of priorities for solicitations and funding is also informed by DOE workshops, advisory groups, federal budget priorities, independent reports, and interagency discussions and documents, including the Strategic Plan and workshop reports of the National Nanotechnology Initiative, or NNI.

With respect to major facilities, the development and operation by DOE of five Nanoscale Science Research Centers represents by far the largest component of the NNI investment in scientific infrastructure. Each of these centers serves as a resource to the entire scientific community, including researchers from other federal

agencies such as the Environmental Protection Agency, and provides researchers access based on the scientific merit of their proposals. These centers are collocated with other major capabilities such as x-ray synchrotrons, neutron scattering facilities, electron microscopy centers, and advanced computing facilities to maximize the advantage of those tools for nanoscience research.

While not their primary research mission, these user facilities will enable work, possible nowhere else in the United States, in environmental, health, and safety issues by providing widely-accessible capabilities for advanced synthesis, characterization, and properties measurement. Four of the NSRCs have completed construction of their specially-designed buildings and are now in operation and the fifth is still under construction.

Furthermore, DOE fully expects the Nanoscale Science Research Centers themselves to be “best in class” with respect to their own environmental, health, and safety practices. Just over a year ago, in September 2005, the Secretary of Energy issued a formal Secretarial Policy Statement on Nanoscale Safety, which I would ask to have included in the record, and it is attached to my testimony.

National Laboratory staff with environmental, health, and safety responsibilities at the Nanoscale Science Research Centers also constitute a working group which meets and teleconferences on a regular basis to share information and best practices.

Interagency coordination has provided very valuable input in defining DOE’s nanotechnology activities. The Department of Energy has participated in the NSET Subcommittee since the subcommittee’s genesis in 2000, and prior to that was a member of the precursor Interagency Working Group of the same name. And in fact, DOE was one of the six initial agencies involved. The development of plans for the Nanoscale Science Research Centers, in particular, was in part a response to the need identified by the interagency group for such major facilities

I hope this testimony provides a fuller awareness of DOE’s many activities in the field of nanoscience, including our attention to the environmental, health, and safety aspects

I appreciate your time and would be glad to address any questions you may have.

[The prepared statement of Dr. Carim follows:]

PREPARED STATEMENT OF ALTAF H. CARIM

Mr. Chairman, and Members of the Committee, good morning and thank you for the opportunity to speak with you today about nanotechnology programs at the Department of Energy. My name is Altaf Carim, and I manage major nanoscience user facilities and coordinate nanoscience activities in the Office of Science at DOE. The longstanding support of this committee for scientific research and development, including that carried out within the Office of Science, is deeply appreciated. Nanoscale science and technology is a key area among those encompassed by the American Competitiveness Initiative. Collectively, these efforts constitute vital investments essential to maintaining U.S. leadership in innovation and its associated economic benefits.

The mission of DOE’s Office of Science is “. . .to deliver the remarkable discoveries and scientific tools that transform our understanding of energy and matter and advance the national, economic, and energy security of the U.S.” To address this mission, the Office of Science includes key portfolio components in two types of activities: fundamental research in support of long-term energy security and discovery science that enables the DOE missions, and forefront scientific user facilities for the Nation which provide the infrastructure for world leadership in science. Accordingly, our nanotechnology activities include both support of basic research at universities

and National Laboratories, and the development and operation of major facilities for nanoscale research.

Nanotechnology research programs at DOE are part of the broad portfolio of programs in the Office of Science, and are supported through submissions to our core research program (the equivalent of a broad agency announcement) as well as through a variety of other occasional solicitations. Only a few such solicitations have concentrated specifically on nanotechnology. The Office of Science also has a small program that supports research on the ethical, legal, and societal issues in two primary areas: biotechnology and nanotechnology. Broadly, decisions on research programs are made through peer review and merit evaluation and through program managers' judgments on portfolio balance. The determination of priorities for solicitations and funding is also informed by DOE workshops, advisory groups, federal budget priorities, independent reports, and interagency discussions and documents, including the Strategic Plan and workshop reports of the National Nanotechnology Initiative (NNI).

Procedures and criteria in the solicitation selection process are consistent with the Code of Federal Regulations at 10 CFR Part 605, with selection and evaluation based on the following criteria which are listed in descending order of importance:

- (1) Scientific and/or technical merit or the educational benefits of the project;
- (2) Appropriateness of the proposed method or approach;
- (3) Competency of applicant's personnel and adequacy of proposed resources;
- (4) Reasonableness and appropriateness of the proposed budget; and
- (5) Other appropriate factors, established and set forth in a notice of availability or in a specific solicitation.

With respect to major facilities, the development and operation by DOE of five Nanoscale Science Research Centers represents by far the largest component of the NNI investment in scientific infrastructure. Each of these centers serves as a resource to the entire scientific community (including researchers from other federal agencies such as the Environmental Protection Agency) and provides researchers access based on the scientific merit of their proposals. The Nanoscale Science Research Centers are collocated with other major capabilities such as x-ray synchrotrons, neutron scattering facilities, electron microscopy centers, and advanced computing facilities to maximize the advantage of these tools for nanoscience research.

While not their primary research mission, these user facilities will enable work—possible nowhere else in the United States—in environmental, health, and safety issues by providing widely-accessible capabilities for advanced synthesis, characterization, and properties measurement. Four of the NSRCs have completed construction of their specially-designed buildings and are now in operation at Argonne National Laboratory, Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, and jointly at Sandia and Los Alamos National Laboratories. The fifth, at Brookhaven National Laboratory, is still under construction.

Further, DOE fully expects the Nanoscale Science Research Centers to be “best-in-class” with respect to their own environmental, health, and safety practices. Just over a year ago, in September 2005, the Secretary of Energy issued a formal Secretarial Policy Statement on Nanoscale Safety, which I would ask to have included in the record (DOE P 456.1, attached). National Laboratory staff with environmental, health, and safety responsibilities at the NSRCs also constitute a working group which meets and teleconferences on a regular basis to share information and best practices.

Interagency coordination has provided very valuable input in defining DOE's nanotechnology activities. The Department of Energy has participated in the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the National Science and Technology Council from the subcommittee's genesis in 2000, and prior to that was a member of the precursor Interagency Working Group of the same name—in fact, DOE was one of the six initial agencies involved in NSET and the NNI, which has now grown to encompass 25 entities. The development of plans for the Nanoscale Science Research Centers was in part a response to the need identified by the interagency group for such major facilities. DOE is actively involved in the NSET subcommittee itself, on which I currently serve as Co-Chair, and its various working groups, including that on Nanotechnology Environmental and Health Implications. DOE and national laboratory staff also participate in related activities such as development of standards necessary for effective understanding of environmental, safety, and health implications through organizations like the American National Standards Institute.

I hope this testimony provides a fuller awareness of DOE's many activities in the field of nanoscience, including our attention to the environmental, health, and safety

aspects of this vital area of science. I appreciate your time and would be glad to address any questions you may have.

Attachment:

U.S. Department of Energy
Washington, D.C.

POLICY

DOE P 456.1

9-15-05

SUBJECT: SECRETARIAL POLICY STATEMENT ON NANOSCALE SAFETY

PURPOSE AND SCOPE

The safety of its employees, the public, and the environment is the Department's number one priority. This policy statement is issued to establish a framework for working safely with nanomaterials.

Nanomaterials exhibit unique properties that can affect physical, chemical and biological attributes. Much of the scientific information on the safety, health and environmental hazards of working with these materials is yet to be determined. With the establishment of the Department's Nanoscale Science Research Centers and other emerging programs, research and development in nanoscience will increase significantly for the foreseeable future.

POLICY

The Department of Energy (DOE) requires that all work with nanomaterials be conducted in a safe and responsible manner that protects workers, the public, and the environment. Thus, the Department must be prudent and follow a cautious approach in the production, use, and disposition of nanomaterials.

It is imperative that the Department's work with nanomaterials be conducted in a manner that encompasses the following attributes:

- DOE will adopt and implement, as appropriate, both existing and future environment, safety and health best practices, "National Consensus Standards," and guidance relating to nanotechnology developed by recognized standard-setting organizations. Further, any existing DOE Directives and Standards which contain provisions that are relevant to nanotechnology work must be appropriately applied.
- DOE and its contractors will identify and manage potential health and safety hazards and potential environmental impacts at sites through the use of existing Integrated Safety Management Systems, including Environmental Management Systems.
- DOE organizations working with nanomaterials will stay abreast of current research and guidance relating to the potential hazards and impacts of nanomaterials, and will ensure that this best current knowledge is reflected in the identification and control of these potential hazards and impacts at their facilities.
- DOE will continue to both support research on the environmental and safety and health impacts of nanomaterials, and participate in government-wide activities aimed at identifying and resolving potential environmental, safety, and health issues.

AVAILABLE ONLINE AT
www.directives.doe.gov

INITIATED BY:
Office of Environment, Safety and Health

RESPONSIBILITIES

Everyone involved with nanotechnology research and development activities shares responsibility for protecting the safety and health of workers and the public, and in safeguarding the environment from the hazards presented by the conduct of their activities. Authorized DOE employees (or personnel) are responsible for conveying to contractors and grantees the expectation that appropriate programs must be in place to maintain a level of worker, public, and environmental safety consistent with the intent of this policy.



SAMUEL W. BODMAN
Secretary of Energy

BIOGRAPHY FOR ALTAF H. (TOF) CARIM**Education**

S.B. in Materials Science and Engineering, Massachusetts Institute of Technology, 1982

M.S. in Materials Science and Engineering, Stanford University, 1984

Ph.D. in Materials Science and Engineering, Stanford University, 1989

Experience

Tof Carim joined the Office of Basic Energy Sciences at DOE in September 2001 as a Program Manager with primary responsibility for activities in the structure and composition of materials. His present duties include serving as the DOE program manager for five Nanoscale Science Research Center user facilities, representing DOE on and co-chairing the interagency Nanoscale Science, Engineering, and Technology subcommittee of the National Science and Technology Council, and overseeing operations of three electron beam micro-characterization user facilities.

Prior to joining DOE, Dr. Carim was at Pennsylvania State University (Penn State), where he was on the faculty for eleven years, most recently as Chair of the Electronic and Photonic Materials Program. He previously held summer positions at Bell Laboratories and the Xerox Palo Alto Research Center, did graduate work under support from Philips Research Laboratories Sunnyvale, held a post-doc at the Philips Natuurkundig Laboratorium in The Netherlands, and for two years was a faculty member at the University of New Mexico. He also was a visiting investigator at the Carnegie Institution of Washington on a sabbatical leave.

Dr. Carim's primary expertise is in microstructural and microchemical characterization of materials, with research contributions in a variety of areas including semiconductor interfaces, superconducting and ferroelectric oxide thin films and ceramics, crystal structure determination, crystalline defects, joining of ceramics and composites, development of anisotropic microstructures, electron holography, and morphology of nanoparticles and nanowires. He has authored or co-authored over 85 research publications in these areas, including two book chapters, has edited two volumes, and has given more than 70 conference, seminar, and other presentations. He has been active in numerous professional societies, has organized a number of technical meetings and symposia, and has held editorial roles with several journals.

His awards and honors include recognition as an Office of Naval Research Young Investigator and receipt of an AIST Foreign Researcher Invitation to lecture in Japan.

Chairman BOEHLERT. Thank you.

Dr. Maynard.

STATEMENT OF DR. ANDREW D. MAYNARD, CHIEF SCIENCE ADVISOR, PROJECT ON EMERGING NANOTECHNOLOGIES, WOODROW WILSON INTERNATIONAL CENTER FOR SCHOLARS

Dr. MAYNARD. Thank you, Chairman Boehlert, Ranking Member Gordon, and Members of the Committee for holding this hearing and for inviting me to speak. My name is Andrew Maynard. I am the chief science advisor for the Project on Emerging Nanotechnologies at the Woodrow Wilson International Center for Scholars, and this is also a partnership with the Pew Charitable Trusts. But obviously, my comments here are my own personal opinions.

I have had over 15 years research experience looking at nanoscale materials. I have also spent some time in the Federal Government, and I have had the great pleasure of co-chairing the NEHI Working Group at its inception with my colleague, Dr. Alderson, who is sitting here.

I would like to begin my testimony by telling you a story.

Imagine a successful businessman who decides to build a new mansion. He gathers together 20 of the best builders in America and tells them to construct his dream home. Sure enough, the details within the mansion are impeccable: Italian marble countertops, vaulted ceilings, exotic hardwood floors. Yet, without the direction of an architect or master plan, the overall building is an incoherent mess.

The point, I think, is obvious: you can't embark on a complex project unless you know where you are going and have at least some idea of how to get there. Yet, this seems to be where we are with research aimed at ensuring the safety of emerging nanotechnologies.

Without a doubt, the Federal Government is funding innovative and ground-breaking research in this area. As my colleagues on this panel have just alluded to, you have heard some excellent examples of what they are doing. But these programs arise from the vision of individual scientists and research leaders within the agencies, and only coincidentally give the fleeting illusion of coherence.

Nanotechnology, as has already been said, is no longer a scientific curiosity. It is already in the workplace, the environment, and the home. If we are to realize the benefits, we need a master plan for identifying and reducing potential risks. This plan should include a top-down research strategy, sufficient funding to do the job, and mechanisms to ensure resources are used as effectively as possible.

Let me address each of those points in turn.

Nanotechnology, as my colleague from EPA has said, is complex. In fact, it is far too complex for disjointed, bottom-up research agendas to answer critical questions on safety. The only viable alternative is a top-down, strategic research framework. This should

identify what needs to be done and when in order to provide regulators, industry, and others with the knowledge they need to ensure safe nanotechnologies.

Without the high-level perspective embodied in a top-down strategy, the emergence of safe nanotechnologies will be coincidental rather than intentional. But a strategy without sufficient resources will be ineffective. In my estimation, the Federal Government needs to invest a minimum of \$100 million in targeted research over the next two years in order to lay a strong science-based foundation for safe nanotechnology. This is largely in addition to current research funding, which, from my analysis, is closer to \$11 million per year rather than the National Nanotechnology Initiative's stated \$37 million to \$44 million per year.

Targeted research will address specific problems involving the potential impact of nanotechnology, but it also must be complemented by more basic exploratory research that develops the scientific knowledge needed to identify and address future risks.

And finally, mechanisms. Mechanisms are needed to support and enable the right research. These must ensure targeted research is led by agencies charged with protecting human health and the environment and supported by those agencies with the resources and the ability to do the job. But they must also support partnerships that provide innovative solutions to new challenges. In particular, government and industry need to work together to address specific issues, and on this point, I am recommending that a jointly funded nanotechnology and health impact research initiative is established within the Health Effects Initiative—Institute. Sorry.

So in closing, I come back to the fundamental question driving this hearing: "Do federal agencies have a coherent, adequately resourced research strategy, which will answer the questions industry needs to develop nanotechnology safely and which will ensure the public that nanotechnology is being managed wisely?"

If the report that we just had released this morning from the NEHI Working Group is anything to go by, I must conclude that there is still a long, long way to go. Lists of research needs are useful, and I don't want to detract from the expertise represented in this report. I think it is a very useful report. But a list is not a research strategy, and without a strategy, it becomes very, very hard, indeed, to differentiate truly relevant research from that which, in all honesty, isn't relevant at all.

In the meantime, people are asking, "What do I do to ensure the safety of nanotech products?" To answer them, the government needs a master plan, and it needs it soon.

Thank you.

[The prepared statement of Dr. Maynard follows:]

PREPARED STATEMENT OF ANDREW D. MAYNARD

I would like to thank Chairman Sherwood Boehlert, Ranking Member Bart Gordon, and the Members of the House Committee on Science for holding this hearing on "Research on Environmental and Safety Impacts of Nanotechnology: What Are the Federal Agencies Doing?"

My name is Dr. Andrew Maynard. I am the Chief Science Advisor to the Project on Emerging Nanotechnologies at the Woodrow Wilson International Center for Scholars. I am an experienced researcher in the field of nanomaterials and their environmental and health impacts, and have contributed substantially in the past fifteen years to the scientific understanding of how these materials might lead to new

or different environmental and health risks. I was responsible for stimulating government research programs into the occupational health impact of nanomaterials in Britain towards the end of the 1990's and have spent five of the past six years developing and coordinating research programs at the Centers for Disease Control and Prevention (CDC) National Institute for Occupational Safety and Health (NIOSH) that address the safety of nanotechnologies in the workplace. While at NIOSH, I represented the agency on the Nanoscale Science, Engineering and Technology (NSET) Subcommittee of the National Science and Technology Council (NSTC), and was co-chair of the Nanotechnology Environmental and Health Implications (NEHI) Working Group from its inception.

The Project on Emerging Nanotechnologies is an initiative launched by the Woodrow Wilson International Center for Scholars and The Pew Charitable Trusts in 2005. It is dedicated to helping business, government and the public anticipate and manage the possible health and environmental implications of nanotechnology. As part of the Wilson Center, the Project on Emerging Nanotechnologies is a non-partisan, non-advocacy organization that collaborates with researchers, government, industry, non-governmental organizations (NGOs), and others concerned with the safe applications and utilization of nanotechnology.

Our goal is to take a long-term look at nanotechnologies; to identify gaps in the nanotechnology information, data, and oversight processes; and to develop practical strategies and approaches for closing those gaps and ensuring that the benefits of nanotechnologies will be realized. We aim to provide independent, objective information and analysis that can help inform critical decisions affecting the development, use, and commercialization of responsible nanotechnologies around the globe.

In short, both the Wilson Center and The Pew Charitable Trusts believe there is a tremendous opportunity with nanotechnology to "get it right." Societies have missed this chance with other new technologies and, by doing so, have made costly mistakes.

As a scientist, I am awed by the vast potential of nanotechnology. I also understand the thrill of making new discoveries and turning them into societal or economic gain. But through my work in occupational health, I also understand the very real dangers of proceeding without due caution. Make no mistake, nanotechnology *is* different, and there *will* be some materials and products developed under this banner that have the potential to cause harm. The challenge we face is how to recognize and manage this possibility ahead of time and deal with it. The stakes are high: not only are human health and the environment potentially at risk, but so is the "health" of nano-commerce. If investors and consumers reject nanotechnology through fear and uncertainty, missed opportunities in areas like medical treatment and energy production could deal a severe blow to the quality of life and the future economic well-being of this country.

Are current federal and private research efforts adequate to address concerns about environmental and safety impacts of nanotechnology? Are there gaps in the portfolio of federal research currently underway; if so, in what areas?

The long-term solution must be to reduce uncertainty about the possible health and environmental impacts of nanotechnology through systematic scientific research. Perhaps uniquely in regards to an emerging technology the Federal Government and industry have moved to understand the potential risks of nanotechnology at an early stage. The *21st Century Nanotechnology Research and Development Act*¹ and the NEHI Working Group within NSET are testaments to the attempts of this government to act early to minimize potential risks. Yet these good intentions do not seem to have translated into hard information regarding how to avoid risks and develop safe nanotechnologies. The fact is that nanotechnology is a reality *now*—in workplaces and in the marketplace: Every day, people are asking questions like "how safe is this product?", "how do I protect myself?", and "what happens to this material in the environment?" These are questions that we do not yet have answers for, and for which we do not yet have a clear pathway to finding answers anytime soon. Our inability to provide clear and timely answers can ultimately jeopardize the ability of government and industry to reap the economic and social benefits of billions of dollars of R&D investments.

Part of the problem is that nanotechnology is complex—no single agency, research group or even scientific discipline is able to grapple with the challenges it presents without collaborating and working with others. This is not a problem we can solve

¹ U.S. Congress (2003). *21st Century Nanotechnology Research and Development Act* (Public Law 108–153), S.189 Washington DC, 108th Congress, 1st session.

piecemeal—effective solutions will require top-down direction and coordination if we are to remove the uncertainty surrounding nanotechnology and potential risk.

In a recent study, *Nanotechnology: A Research Strategy for Addressing Risk*, I considered what needs to happen if critical research questions are to be addressed.² Drawing on previously published papers from government, industry, academia and NGOs, the report—which is included with this testimony—identifies and prioritizes critical research needs and makes specific recommendations on how to develop an effective strategic research framework. In assessing the current risk research situation, it became very clear that current federal coordination of nanotechnology research is not sufficient to ensure that timely and relevant information on minimizing and managing nanotechnology's risks is being developed.

In particular, the relevant agencies are under pressure, because they are under-resourced and struggling without adequate leadership or broad strategic direction. I see no evidence of foresight; of the government looking longer-term to identify emerging risks that may appear as nanotechnology becomes more complex and converges with biotechnology. Without better foresight, there is little hope that the government will be positioned to underpin regulation with good science, or provide solid answers to questions that the public will inevitably raise about the risks of nanotechnologies. Individual agencies such as NIOSH, the Environmental Protection Agency (EPA), the National Institutes of Health (NIH) and the National Science Foundation (NSF) are doing their best to develop research programs from the bottom-up—in some cases with very limited resources. But these disconnected research programs will not make a significant difference in ensuring safe nanotechnologies without sweeping changes to the way nanotechnology risk research is directed and supported at the federal level.

The current approach leads to some perplexing oddities. For example, it is widely accepted that research into assessing and preventing health risks in the workplace is critical to the success of nanotechnologies. However, the anticipated increase in risk-related research funding for the National Science Foundation between 2006 and 2007 (an increase of \$3.6 million, from \$22.1 million to \$25.7 million), far exceeds the total requested nanotechnology risk research budget for the National Institute for Occupational Safety and Health in 2007 (\$3 million).³ If these figures accurately reflect the Federal Government's current priorities, then it is clear that ensuring safe nanotechnology workplaces is not high on the list—particularly since the mandate of NSF is basic research and not mission-driven environmental and human-health studies.

Of course, numbers alone can be misleading: What is important is the research that those numbers represent. It is obvious that without knowing where you are, you cannot plan how to get where you want to be. If federal research addressing the potential risks of nanotechnology is to be strategic, transparent and relevant, we need to know what is being done and what is being missed. Unfortunately, information as to what risk-related research is currently being carried out is not readily available from or even within the Federal Government. National Nanotechnology Initiative (NNI) representatives have noted that it is hard to tease out risk-related projects from the general mix of the government's nanotechnology research portfolio. However, without a more precise understanding of what U.S. Government funded investigators are studying, the reported figures tell us nothing about whether the right questions are being asked—and answered—in order to ensure nanotechnology's safe management. It is important to emphasize that this research by the government is being supported by public funds and it is ultimately the public—as workers or consumers, for instance—that may bear many of the potential risks related to nanotechnology. Project-by-project data on what the government is funding to understand and mitigate risks should be placed in the public realm now.

What should be the priority areas of research on environmental and safety impacts of nanotechnology? How should the responsibility for funding and conducting this research be divided among the federal agencies, industry, and universities?

Recognizing this information gap, last year the Project on Emerging Nanotechnologies compiled and published an inventory of current nanotechnology

²Maynard, A.D. (2006). *Nanotechnology: A Research Strategy for Addressing Risk*, PEN 03 Washington DC, Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars. Available at www.nanotechproject.org.

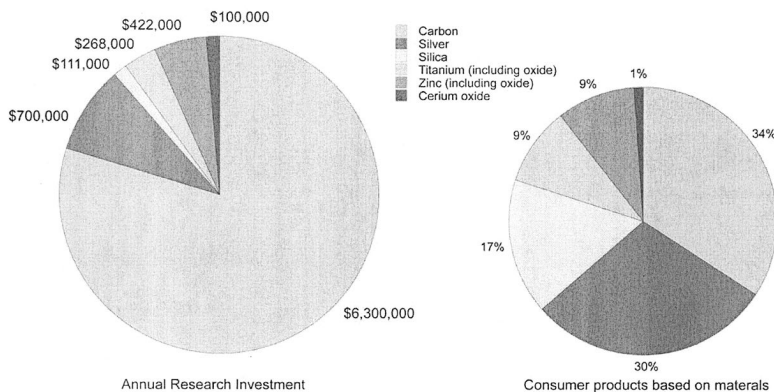
³NSET (2006). *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry Supplement to the President's FY 2007 Budget*, Washington, DC, Subcommittee on Nanoscale Science, Engineering and Technology, Committee on Technology, National Science and Technology Council.

risk-related research.⁴ The inventory is publicly accessible on-line, fully searchable, and classifies research to allow a clear picture of what is currently being done. The inventory first and foremost confirms that a substantial body of research is being funded to try and understand the potential impacts of nanotechnology on human health and the environment. In 2005, we estimate that the annual U.S. Federal Government in research with some relevance to nanotechnology risks was over \$30 million. However, it is unclear how relevant this research is to reducing the current uncertainty over nanotechnology's health and environmental impacts, providing guidance for emerging oversight regimes at agencies such as EPA and FDA, or answering increasing numbers of public questions and concerns over the safety of nanotech-related products and applications.

Two examples serve to highlight an apparent disconnect between the Federal Government's research agenda and what is needed to illuminate any hazards related to nanotechnology. The first example draws on the Project on Emerging Nanotechnologies' inventory of nanotechnology-based consumer products,⁵ and compares the prevalence of nanomaterials in these products to research into their potential impacts. In Figure 1, I compare research into the impact of six nanomaterials—carbon, silver, silica, titanium, zinc and cerium—to the number of consumer products known to be using these materials.

Although this is a very subjective exercise, it shows the vast majority of the *material-specific* risk research is focused—disproportionately it would seem—on carbon-based nanomaterials. At the time of the analysis, carbon-based nanomaterials accounted for just 34 percent of listed consumer products, while silver accounted for 30 percent of listed products, and silica and metal oxides such as silica, titanium dioxide, zinc oxide and cerium oxide accounted for 36 percent of listed products. In other words, risk research does not appear to be in step with current market realities.

Figure 1.
Nanotechnology Environmental Safety and Health research funding for six classes of engineered nanomaterials, compared to consumer products using those materials (based on 2005 data)



© 2006. All rights reserved by Woodrow Wilson International Center for Scholars

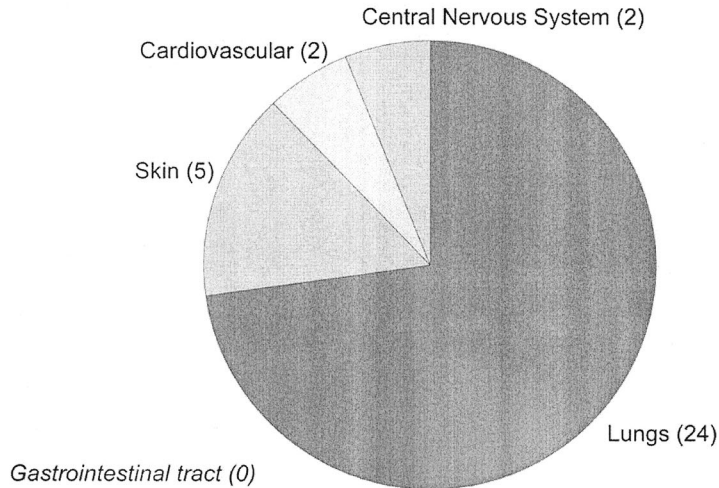
The second example considers the number of research projects that are probing the potential effects of nanomaterials on different parts of the body—the lungs, the skin, the central nervous system, the cardiovascular system and the gastrointestinal tract. Figure 2 indicates that current human hazard research appears to focus heavily on nanomaterials in the lungs (24 projects), while no projects are specifically addressing the potential effects of nanomaterials in the gastrointestinal tract. Given the large number of current and future nano-products that are intended to be

⁴Nanotechnology Health and Environmental Implications: An Inventory of Current Research. www.nanotechproject.org/18 Accessed September 12th 2006.

⁵A Nanotechnology Consumer Products Inventory. www.nanotechproject.org/consumerproducts Accessed September 12th 2006.

eaten—such as food and nutritional supplements—this is a curious and serious omission.

Figure 2.
Nanotech-risk research projects on specific areas of the body (based on 2005 data)



©2006 All rights reserved by Woodrow Wilson International Center for Scholars

These examples indicate that current federally funded research is not addressing the general range of risks that *may already be present in the market* and that risk research is not guided by a careful consideration of needs—today or tomorrow. Why is there so little research on nanomaterials in use now? Is the emphasis on lung impacts due to careful consideration of relative risks, or because pulmonary toxicologists are more active in this field?

Having cataloged information on current risk-research, the Project on Emerging Nanotechnologies (PEN) was able to go back and check the validity of published government funding figures. Comparing estimates of federal spending on nanotechnology risk research from our research inventory to figures published by NSET tells an interesting story. Table 1 compares the NSET figures with PEN-estimated annual funding for research which is *highly relevant* to understanding risk and research which has *some degree of relevance*.

Table 1.
U.S. federal government annual spending on nanotech-risk R&D (\$millions)⁶

Agency	NNI-estimated risk-related annual R&D	PEN-estimated risk-related annual R&D (all relevant research)	PEN-estimated risk-related annual R&D (highly relevant research)
NSF	24.0	19.0	2.5
DOD	1.0	1.1	1.1
DOE	0.5	0.3	0
HHS (NIH)	3.0	3.0 [†]	3.0 [*]
DOC (NIST)	0.9	1.0	0
USDA	0.5	0.5	0
EPA	4.0	2.6	2.3
HHS (NIOSH)	3.1	3.1 ^{**}	1.9 ^{***}
DOJ	1.5	0	0
Totals	38.5	30.6	10.8

©2006 All rights reserved by Woodrow Wilson International Center for Scholars

Annual spending estimated from the National Nanotechnology Initiative, and the Project on Emerging Nanotechnologies (PEN). Highly relevant research (right hand column) is specifically focused on health and environmental risks associated with engineered nanomaterials, and is included in the broader analysis of all relevant research (middle column). NNI figures are estimated budgets for October 2005 – September 2006, while PEN figures are estimated expenditure for January – December 2005. [†]Estimate, based on research within the National Toxicology Program. ^{**}Based on aggregated funding reported by NNI. ^{***}Estimated from the percentage of projects highly relevant to engineered nanomaterials.

⁶ Maynard, A. D. (2006). *Nanotechnology: A Research Strategy for Addressing Risk*, PEN 03 Washington DC, Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars. Available at www.nanotechproject.org.

Highly-relevant research covers projects with the specific aim of understanding the potential risks of nanotechnology, and includes areas such as using a life-cycle approach to evaluate the impact of future nanotechnologies (EPA), and evaluating assessment methods for nanoparticles in the workplace (NIOSH). On the other hand, *research with some degree of relevance* includes projects that are not focused on nanotechnology risk, but nevertheless have the potential to shed some light on our understanding of risk. Examples include studying the formation of nano-droplets (NSF), developing biosensors for metals (EPA) and controlling exposure to welding fumes (NIOSH).

There is close agreement between the NSET estimate for *highly-relevant* risk research and the Project on Emerging Nanotechnologies estimate of research with *some degree of relevance*. When the Project on Emerging Nanotechnologies estimate of research that is *highly relevant* to engineered nanomaterials is compared to the NSET estimate, the gap widens considerably. Based on all available information, we estimate that only \$11 million per year is being spent on research that is *highly relevant* to nanotechnology risks, compared to NSET's estimate of \$38.5 million per year. That gap is too large to be explained by the different reporting periods or a lack of agency disclosure.

What elements should the forthcoming report on research needs produced by the National Nanotechnology Environmental and Health Implications Working Group contain to adequately guide federal research investment in this area? What additional steps are needed to improve management and coordination of federal research on the environmental and safety impacts of nanotechnology?

The evidence before us strongly suggests that current federal research efforts are not adequate to address concerns arising about the environmental, health and safety impacts of nanotechnology. There are clear gaps in the research portfolio in determining potential hazard, evaluating exposure, controlling releases of nanomaterials,

determining potential impact and managing risk. But I am more concerned over the lack of an apparent top-down strategy that couples risk research to real information needs. Without such a strategy, it is next to impossible to identify clearly where the gaps are and how best to address them. Implicit in a strategy is the setting of hard priorities, the linking of these priorities to actual multi-year funding levels, and the development of metrics to measure results over time. There is a large difference between a strategy and a list of research needs.

A government strategy must also consider and integrate industry issues and, ultimately, enable collaborative funding. Much less information is available on industry-based risk research and testing programs. Some initiatives shine out, such as the research consortium led by DuPont to develop measurement methods and research supported by the International Council On Nanotechnology (ICON) into good workplace practices. But these are the exception—most nanotechnology industries are looking to the government for guidance on what should be done and are coming up against a brick wall. This means that we not only lack a coherent government strategy, but we lack a coherent public-private sector strategy, and we certainly have no international strategy to address risks in a timely manner.

With the right leadership from the Federal Government, effective research programs and partnerships can be developed that will lead to safe nanotechnologies. In the attached report, I make a number of recommendations on what needs to be done in the next two years. Here, I would like to focus on three specific recommendations for developing a strong federal research agenda that simultaneously reduces uncertainty as fast as possible and serves the needs of regulators, industry and other stakeholders:

- Develop a top-down strategic risk-research framework within the Federal Government;
- Adequately fund strategic risk-focused research, with an investment of at least \$100 million, over the next two years; and
- Support a joint government-industry funded cooperative science organization, with a five-year plan to systematically address the human health impacts of engineered nanomaterials through independent, targeted research.

Although not comprehensive, I believe making advances in each of these three areas, as I will explain in more detail, will lead to effective research programs that serve the needs of various end-users.

Develop a top-down strategic risk-research framework within the Federal Government.

Nanotechnology is no longer confined to the laboratory; it is a commercial reality now.⁷ As our ability to make new materials, devices and products through nanoscale engineering becomes increasingly sophisticated, researchers, workers and the public are raising real concerns over what the possible impacts to their health and the environment will be. These are concerns that can only be addressed through systematic, targeted and coordinated research.

Bottom-up, or investigator and agency-driven research, is highly effective at generating new knowledge. However, it will never have the context and perspective to holistically address issues arising from technology development and implementation. Instead, a top-down approach is essential, one that maps out necessary areas of research, prioritizes critical needs and provides support and direction for research agencies. In effect, a top-level framework is needed that enables scientists and research agencies to do their job as effectively as possible, to the best of their ability.

Where resources are limited, a top-down approach is the only way of ensuring that the necessary research is done within budgetary constraints and in a timely manner. The danger of not coordinating direction and resources from the highest levels is that research becomes unfocused and untargeted—and ultimately ineffective. It is irresponsible to spend millions of dollars on building a better microscope in the name of risk research when we cannot tell workers how effective their respirators are when working with nanomaterials!

An effective top-down strategic framework must identify and prioritize critical research needs within the context of oversight and regulation. But it must also have teeth—it must have the authority to ensure that research priorities can be met

⁷An on-line Project on Emerging Nanotechnologies inventory identifies nearly 300 nanotechnology-based consumer products (www.nanotechproject.org/consumerproducts). These represent the tip of the commercial nanoparticle iceberg. Lux Research estimates that \$32 billion worth of nanotechnology-enabled products were sold in 2005 (www.luxresearchinc.com/press/RELEASE-TNR4.pdf).

through the provision of sufficient resources, the support of key agencies and the use of effective and relevant research and development mechanisms. It also must enable collaboration and partnerships between researchers, agencies and other organizations. As I have mentioned previously: nanotechnology is complex, and progress will only be made by working together.

While the NEHI Working Group has been effective in getting research agencies talking about risk, it has shown little evidence of leadership in setting and implementing a strategic research agenda. Although the NEHI Terms of Reference focus on supportive roles of information sharing and communication,⁸ the Working Group has no clear authority to direct research from the top down. To be truly effective in removing uncertainty surrounding the potential impacts of nanotechnologies, a new interagency oversight group should be established with authority to set, implement and review a strategic risk research framework. This group would be responsible for developing a top-level strategic framework that would serve as a guide for the coordination and conduct of risk-related research in relevant agencies. It would have the authority to set and implement a strategic research agenda and assure that agencies are provided with appropriate resources to carry out their work. The group would direct efforts to provide a strong scientific basis for regulatory decisions, thus bridging the existing gap between the need for oversight and our poor technical understanding of nanotechnology risks. It would also ensure that the results of risk-relevant research are put to practical uses, including education and outreach programs. In addition, the group would ensure that risk-related research is coordinated between industry and government and between the U.S., other countries and international organizations.

In order to establish a long-term research agenda, the group must draw on the expertise of stakeholders, as well as government and non-government experts. I would strongly recommend that the National Academies are commissioned to conduct an independent, rolling review of research needs and priorities, which informs the strategic risk research framework.

Adequately fund strategic risk-focused research, with an investment of at least \$100 million, over the next two years.

Once a research strategy is in place, it must be funded at realistic levels if it is to be successful. In my analysis of short-term strategic needs, I estimated the minimum level of funding needed to address critical questions by estimating the cost of the most important immediate research areas. From this analysis, a minimum of \$100 million should be invested in targeted, highly relevant nanotechnology risk research over the next two years if significant progress is to be made. This is a substantial increase in the estimated \$11 million per year currently being spent on risk-specific research.⁹ Funding should be tied to a top-level strategic risk research framework, and it should support agencies with missions and competencies to assess and reduce harm to people and the environment, such as NIOSH, EPA and the National Institute of Environmental and Health Sciences (NIEHS). But, it should also leverage the research expertise and facilities of agencies such as the Department of Energy (DOE) and NSF.

Critical research is needed that addresses risk assessment, environmental impact, human health impact and hazard prediction. In Table 2, I outline the highest research priorities—based upon my previously published analyses of research needs—and identify agencies that are ideally placed to lead these research efforts.

⁸Interagency Working Group on Nanotechnology Environmental and Health Implications (NEHI WG): www.nano.gov/html/society/NEHI.htm Accessed September 12th 2006.

⁹Maynard, A.D. (2006). *Nanotechnology: A Research Strategy for Addressing Risk*, PEN 03 Washington, DC, Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars. Based on data published in the Project on Emerging Nanotechnologies inventory of nanotechnology EH&S research (www.nanotechproject.org/18). This figure does not include recent increased EPA investment in nanotechnology risk research.

Table 2.
Short-term nanotechnology environmental, safety and health implications research priorities, lead agencies and estimated costs¹⁰

Lead Agency	Short Term Research Goals	Estimated Funding [†]
Cross Agency	<ul style="list-style-type: none"> • Develop research methodologies to proactively address risk • Begin developing appropriate risk assessment tools • Preliminary development of informatics systems for nanomaterials 	7
EPA	<ul style="list-style-type: none"> • Identify sources and routes of exposure and release - environment • Develop and evaluate environmental measurement methods • Preliminary development of appropriate methods for evaluating ecotoxicity • Preliminary development of life cycle analysis tools for engineered nanomaterials • Preliminary investigation of ecotoxicity mechanisms • Preliminary investigation of nanomaterial release into the environment • Begin to study dispersion, transformation, fate, persistence and bioaccumulation in the environment 	20
NIH	<ul style="list-style-type: none"> • Begin to evaluate the toxicity of representative nanomaterials • Preliminary development of appropriate toxicity testing endpoints • Preliminary development of appropriate toxicity testing methods • Begin developing predictive toxicology capabilities • Begin developing computational toxicology for engineered nanomaterials • Preliminary investigation of nanomaterial structure activity relationships 	24
NIOSH	<ul style="list-style-type: none"> • Develop and evaluate human exposure measurement methods • Develop guidance on best possible working practices • Develop and evaluate personal protective equipment • Develop and evaluate respiratory protective equipment • Develop and evaluate process-based controls • Identify sources and routes of exposure and release - workplaces • Develop instrument-based exposure metrics • Develop and evaluate appropriate toxicity screening tests • Develop a preliminary understanding of organ-specific dose • Preliminary research exploring associations between nanomaterials exposure and human health outcomes • Begin to develop methods to control and manage spills • Study the role and significance of routes of entry into the body • Preliminary investigations of nano-specific safety issues • Begin studying transport, transformation and fate in the body • Preliminary evaluation of risk reduction through material substitution 	46
NIST	<ul style="list-style-type: none"> • Preliminary development of appropriate nanomaterials characterization methods • Begin developing measurement and characterization standards • Begin developing standards for terminology and reference materials 	9
Total		106

©2006 All rights reserved by Woodrow Wilson International Center for Scholars
Proposed lead agencies and minimum targeted federal funding levels to address identified short-term research goals. Estimated funding is in \$millions over a two-year period, and includes intramural and extramural funding of risk-specific research. Research goals addressing immediate, medium-term and long-term areas are shaded from dark to light. [†]Estimated funding over 2 years.

¹⁰ Maynard, A. D. (2006). *Nanotechnology: A Research Strategy for Addressing Risk*, PEN 03 Washington DC, Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars. Available at www.nanotechproject.org.

Support the formation of a joint government-industry funded cooperative science organization, with a five-year plan to systematically address the human health impact of engineered nanomaterials through independent, targeted research.

The success of a strategic risk research framework for nanotechnology will depend critically on the mechanisms used to implement research. Federally-funded research must be systematic and targeted, if it is to answer questions being asked by industry and the public. But progress will also depend on collaborating and partnering with other stakeholders—particularly industry.

Industries investing in nanotechnology have a financial stake in preventing harm, manufacturing safe products and avoiding long-term liabilities. Yet, with a few exceptions, most of the questions that need answering are too general to be dealt with easily by industry alone. Perhaps more significantly, the credibility of industry-driven risk research is often brought into question by the public and NGOs as not being sufficiently independent and transparent. It seems that the current state of knowledge is sufficient to cast doubt on the safety of some nano-industries and products, but current information lacks the credibility for industry to plan a clear course of

action on how to mitigate potential risks. Getting out of this “information trap” is a dilemma facing large and small nanotechnology industries alike.

One way out of the “trap” is to establish a cooperative science organization, tasked with generating independent, credible data that will support nanotechnology oversight and product stewardship. The organization would leverage federal and industry funding to support targeted research into assessing and managing potential nanotechnology risks. The success of such an organization would depend on four key attributes:

Independence. The selection, direction and evaluation of funded research must be science-based and must be fully independent of the business and views of partners in the organization.

Transparency. The research, reviews and the operations of the organization must be fully open to public scrutiny.

Review. Research supported by the organization must be independently and transparently reviewed.

Communication. Research results must be made publicly accessible and fully and effectively communicated to all relevant parties.

A number of research organizations have been established over the years that comply with some of these criteria. Yet, perhaps the organization most successful and relevant to nanotechnology is the Health Effects Institute (HEI).

HEI was established in 1980 as a non-profit research institution focused on providing “high-quality, impartial, and relevant science” around the issue of air pollution and its health impacts.¹¹ The Institute is committed to supporting risk-relevant research through anticipating the needs of policy-makers and scientists and by identifying the underlying questions propping up policy arguments and research priorities. Additionally, the production of timely scientific evidence is crucial to allow for decisions to be made within appropriate product development cycles.

The HEI research model is unique in a number of ways. New research projects are chosen based on a *competitive proposal process*. This project selection process is similar to those employed by NSF and NIH, but it includes added attention to the policy relevance of scientific research. Once projects are selected for support, HEI issues *contracts*—not grants—to investigators. This is a unique component of the HEI process, and it allows the organization to benefit from the most creative proposals from the science community but still have much greater control over the scope of work and the final products to ensure their relevance to decisions. Close control over research enables HEI to aggressively manage investigations by monitoring progress and terminating projects that are not meeting established standards.

Once projects are funded, *strict quality control* is followed. Both HEI staff and independent investigators audit and review project quality. HEI’s strict adherence to their quality control guidelines and rigorous peer reviews serves as potent defense against possible detractors. While this quality control does come at the cost of burdening investigators with more numerous reviews, it also serves to strengthen the validity of the data when applied in the policy realm and has raised HEI to a place among the most respected research organizations in the world.

Finally, supported research undergoes *independent peer review and policy relevance critique*. This process allows for thorough review prior to publication of a comprehensive report by HEI. The findings of any dissenting critiques are published along with final reports. In turn, all results are openly published in HEI’s reports, both positive and negative, so that industry professionals and policy-makers can better understand how the investigators reached their conclusions.¹² Since these results are presented in a highly transparent manner and are available at varying levels of detail, they are accessible to a wide variety of audiences. In addition, after reports are released, HEI monitors their use and strives to ensure that the full range of conclusions is considered by decision-makers in order to maintain their scientific integrity.¹³

HEI has funded over 250 studies in North America, Europe and Asia on a variety of topics, including carbon monoxide, air toxics, nitrogen oxides, diesel exhaust, ozone and particulate matter. The organization credits its success to five key factors: effective governance, joint industry-government funding, quality science, no advo-

¹¹ Health Effects Institute (HEI) Website. “What is the Health Effects Institute.” Available at www.healtheffects.org/about accessed July 27th 2006.

¹² HEI Annual Report 2005, p. 6.

¹³ HEI Annual Report 2005, p. 6.

cacy and communication. Members constituting the HEI Board of Directors are chosen based upon their independence of any interests that could constitute bias, and this level of independence is extended down through the committees and staff. Individuals selected to the board are dually approved by stakeholders on both sides. The board of directors is charged with screening for potential conflicts of interest, overseeing staff, appointments to panels and the selection of researchers.

The HEI model is ideally suited to generating the credible and relevant information necessary to develop safe nanotechnologies. Developing a program using such a model would complement federal research into the potential risks of nanotechnology and would provide industry and regulatory agencies with needed information on managing possible health and environmental impacts. HEI could well be used as a template for establishing a separate “Nanotechnology Effects Institute.” But it would be more expedient to develop a nanotechnology risk research program within HEI. For this to occur, four conditions would need to be met:

- **Commitment by HEI to develop a nanotechnology risk research program.**

Informal discussions with HEI have indicated a willingness to consider extending the Institute’s research portfolio to addressing nanotechnology and potential risks. Successful development of such a research program will depend on long-term funding commitments from government and industry and a targeted, relevant research agenda.

- **Commitment from the Federal Government to jointly fund research.**

A successful program will depend on matched federal-industry funding, over a minimum of five years. Federal funding levels of at least \$10 million over that time frame will be needed to ensure a coherent, relevant and influential research program and to attract industry funding. Currently, most government funding for HEI comes from EPA, with one half from the research arm and one half from the program/regulatory side. This allows for a tight link between research and regulation and the provision of a solid scientific underpinning for oversight. This approach can be followed for nanotechnology but should be expanded to consider research needs of agencies beyond EPA, such as FDA.

- **Commitment from industry to jointly fund research.**

Likewise, establishing a successful research program will depend on a matching financial commitment from industry of at least \$10 million over the next five years. Provisions should be made to integrate research issues from small business and start-up firms.

- **A relevant and robust strategic research agenda.**

The success of a HEI-based nanotechnology risk research program will depend on identifying research areas that complement federal research, while responding directly to industry needs. Based on my analysis of critical research needs, I would propose that the initial emphasis of such a research agenda should focus on understanding and reducing the potential toxicity of engineered nanomaterials in humans. Table 3 lists a suite of research projects, along with estimated funding levels, which could form the backbone of a credible five-year research program. Of course, an expert oversight committee convened by an organization like HEI could—with broad input from the science and regulatory communities—review these priorities rapidly and finalize a set of targeted priorities to be sought in a first Request for Applications.

It must be emphasized that this proposed program would complement, and not replace, either federal or industry research programs and that the estimated \$20 million over five years is in addition to funding levels recommended for government-specific research.

Table 3.
Proposed components of a five-year cooperative government-industry nanotechnology risk research program

Thematic Area	Goals	Estimated funding (5 years, \$ millions)
Begin to evaluate the toxicity of representative nanomaterials		
	<i>Ascertain the applicability of the fiber paradigm to high aspect-ratio engineered nanomaterials</i>	\$2M
	<i>Develop a preliminary ranking of the toxicity of commercially available nanomaterials, compared to non-nano benchmark materials</i>	\$2M
	<i>Develop a systematic understanding of preferential protein adsorption on representative nanoparticles in biological systems, and evaluate subsequent impact on biological activity</i>	\$1M
Preliminary development of appropriate toxicity testing methods		
	<i>Develop and validate a suite of in vitro tests for evaluating the potential toxicity of new engineered nanomaterials</i>	\$2M
Preliminary investigation of nanomaterial structure activity relationships		
	<i>Systematically evaluate the association between discontinuous particle size-dependent properties (such as quantum confinement) and toxicity</i>	\$2M
	<i>Evaluate the range of biological responses associated with physical and chemical perturbation within classes of nanomaterials in commercial production. Specifically consider variations in surface coatings and treatments, crystallinity and suspension liquid within nanomaterial classes</i>	\$2M
Develop and evaluate appropriate toxicity screening tests		
	<i>Develop and validate a suite of acellular tests for screening potential nanomaterial toxicity</i>	\$1M
Develop a preliminary understanding of organ-specific dose		
	<i>Investigate the relationship between geometric and biologically active surface area as a function of particle size, shape and chemistry</i>	\$2M
Study the role and significance of routes of entry into the body		
	<i>Investigate whether transport along the olfactory nerves is a significant exposure route in humans, and what the potential impact on the central nervous system might be</i>	\$2M
	<i>Establish boundaries on factors that influence nanoparticle penetration through the skin, and study potential health impact as a function of key parameters</i>	\$2M
Begin studying transport, transformation and fate in the body		
	<i>Develop pharmacokinetic models of nanoparticle transport and partitioning in the body, through various routes of exposure</i>	\$2M
TOTAL		\$20M

Conclusions

Nanotechnology is a reality now, and our ability to produce ever-more sophisticated materials, processes and products by engineering at the nanoscale will only increase over the coming years. Yet our understanding of the potential environmental, safety and health impacts of these emerging technologies is rudimentary at best.

Government and industry have been commendably astute in recognizing the possibility of new risks arising from emerging nanotechnologies at an early stage. But over a decade after the first indicators of nanostructured material-specific hazards were published, risk-based research remains poorly focused and under funded. Current federal research programs are unlikely to provide answers where they are most needed, and needed they are—especially since a proper understanding of risks is the only way to assure the emergence of economically viable technologies that do not harm people or the environment.

In this testimony, I have examined where current research strategies are lacking, and what can be done to ensure that future research is effective in reducing uncertainty surrounding the safety of nanotechnologies. In particular, I highlighted the need to develop a top-down strategic risk-research framework within the next six months and the need to adequately fund risk research—with an investment of at least \$100 million over the next two years. I also proposed establishing a five-year, \$20 million joint government-industry risk research partnership through the Health Effects Institute that will complement federal research initiatives.

As the recommendations presented above begin to be implemented, it is clear that a host of questions remain to be addressed, including:

- How are federal agencies ensuring that nanotechnology risk research information is being made widely available to the public, researchers, and small businesses?
- How can the risk-related research needs of small nanotechnology businesses and start-ups be integrated into a comprehensive government-industry strategy?
- How is the Federal Government translating risk-based research into effective guidance on working with and using nanotechnology-based products as safely as possible?
- What plans does the Federal Government have to closely coordinate risk research at a global level?
- What processes are in place that will allow the government to better anticipate and address future risks, especially as nanotechnology becomes more complex and converges with biotechnology?
- How much is the Federal Government spending to design and engineer risks out of nanotechnology processes and products (rather than just addressing them after the fact)?

In closing, let me say that I have tremendous respect for the researchers who are working to understand the potential impacts of nanotechnology on human health and the environment. It is through their efforts that we now know many of the key issues that need to be addressed in order to make nanotechnology safe. However, for these researchers and research directors to be effective, they must be better supported with the necessary financial, human and strategic resources that they need. By taking action now, we have the opportunity to realize the full potential nanotechnology has to offer, without creating a legacy of harm to human health and the environment.

BIOGRAPHY FOR ANDREW D. MAYNARD

Dr. Andrew Maynard serves as the Science Advisor to the Project on Emerging Nanotechnologies. He is internationally recognized as a research leader and lecturer in the fields of aerosol characterization and the implications of nanotechnology to occupational health. He trained as a physicist at Birmingham University (UK), and after completing a Ph.D. in ultra-fine aerosol analysis at the Cavendish Laboratory, Cambridge University (UK) joined the Aerosols Research Group of the UK Health and Safety Executive.

In 2000, Dr. Maynard joined the National Institute for Occupational Safety and Health (NIOSH), part of the U.S. Centers for Disease Control and Prevention (CDC). At NIOSH, he established a groundbreaking research program in ultra-fine aerosol analysis, and was instrumental in developing NIOSH's nanotechnology research program. This research was at the forefront of international scientific efforts to better understand the occupational health implications of nanomaterials, and to develop guidance on workplace exposures in this burgeoning industry. While at NIOSH, Dr. Maynard was a member of the Nanomaterial Science, Engineering and Technology subcommittee of the National Science and Technology Council (NSET). He also co-chaired the Nanotechnology Health and Environment Implications (NEHI) working group of NSET. Both are a part of the National Nanotechnology Initiative (NNI), the federal research and development program established to coordinate the U.S. Government's annual \$1 billion investment in nanoscale science, engineering, and technology.

Dr. Maynard was Co-Chair of the first two international conferences on nanotechnology and occupational health, and is affiliated with many organizations and initiatives exploring the responsible and sustainable development of nanotechnology. He is a member of the Executive Committee of the International Council On Nanotechnology (ICON), and until recently, chaired the International

Standards Organization Working Group on size selective sampling in the workplace. He holds an Associate Professorship at the University of Cincinnati (OH), and is an Honorary Senior Lecturer at the University of Aberdeen (UK). His expertise covers many facets of scientific research and policy, from occupational aerosol sampler design to recommendations on strategic nanotechnology research, as reflected in over 70 professional publications. Dr. Maynard is a regular international speaker on nanotechnology, and frequently appears in print and on radio and television.



September 18th 2006

The Honorable Sherwood Boehlert
Chairman, Science Committee
2320 Rayburn Office Building
Washington, DC 20515

Dear Congressman Boehlert:

Thank you for the invitation to testify before the Committee on Science of the U.S. House of Representatives on September 21st for the hearing entitled "*Research on Environmental and Safety Impacts of Nanotechnology: What are the Federal Agencies Doing?*" In accordance with the Rules Governing Testimony, this letter serves as formal notice of the federal funding I have received in the past three fiscal years related to the hearing topic.

- Between January 2004 and July 2005, I was an employee of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Over this period, my personal salary was \$165,663.
- Between January 2004 and July 2005, I was responsible for directing four specific research projects within the National Institute for Occupational Safety and Health. Research funding associated with these projects was \$595,000 for Fiscal Year 2004 and Fiscal Year 2005, not including investigator Personal Salaries and Benefits.

Sincerely,

Dr. Andrew D. Maynard
Chief Science Advisor, Project on Emerging Nanotechnologies
Woodrow Wilson International Center for Scholars
Washington DC

Project on Emerging Nanotechnologies

ONE WOODROW WILSON PLAZA, 1300 PENNSYLVANIA AVENUE, NW, WASHINGTON, DC 20004-3027 T 202.691.4282 F 202.691.4001 WWW.WILSONCENTER.ORG/NANO
A partnership with THE PEW CHARITABLE TRUSTS



Chairman BOEHLERT. Thank you very much, Dr. Maynard.
Mr. Nordan.

**STATEMENT OF MR. MATTHEW M. NORDAN, PRESIDENT,
DIRECTOR OF RESEARCH, LUX RESEARCH, INC.**

Mr. NORDAN. Good morning, Chairman Boehlert, Ranking Member Gordon, and Members of the Committee, and thank you for inviting me to speak today.

My company, Lux Research, conducts hundreds of interviews and advisory sessions each year with companies that are commercializing nanotechnology. In this testimony, I will attempt to synthesize their views.

Ten months ago, this committee held its first hearing on nanotech EHS risks, and since then, commercialization has shot forward, and academic research on nanoparticle toxicity has broadened. However, when it comes to coordinate government action to address risk, very little has changed, and the status quo remains inadequate.

From the perspective of industry, nanotechnology EHS concerns fall into three categories: real risks, perceptual risks, and regulatory risks. Real risks represent the possibility that nanoparticles may harm workers or consumers or the environment. Although new publications in the last year have somewhat revised judgments about real risks, research is still extremely thin on the ground. Only about one-half of one percent of the 81,000 journal articles on toxicology since 2000 so much as mention nanomaterials.

The second concern, perceptual risks, is the threat that even if nanoparticles were shown to be entirely benign, public skepticism could still make their commercial use untenable. In the United States, consumer perceptions of nanotech remain unchanged. Citizens remain uninformed but favorably predisposed. What has changed is the aggressiveness of non-governmental organizations that are hostile to nanotech, particularly outside the United States. When the French government's Ninetech nanotechnology research center opened in May, protesters stormed conference rooms and accosted scientists on the street.

The final concern seen by industry is regulatory risks, worry that the playing field will shift underneath them. Now this concern isn't what you might expect. Corporate EHS officers consistently want to see regulation that will help them plan, yet regulatory ambiguity persists. While companies are pleased about how the EPA, in particular, has communicated with them, they are also frustrated by how slow the EPA has been to set specific guidance, namely its long-proposed voluntary stewardship program for nanomaterials.

These three concerns, real risks, perceptual risks, and regulatory ambiguity, are adversely impacting nanotech commercialization in the United States. A few large corporations are halting nanotech activities entirely. One Fortune 500 R&D head told us that, "Our CEO decided to postpone new investments in nanotechnology until the FDA decides how it will be handled."

Venture capitalists are beginning to shrink from funding start-ups that face nanotech EHS risks, as prominent nanotech investor Steve Gervitson recently stated. Firms are increasingly banning references to the word "nanotechnology" because of perceptual

risks, even as they pursue nanotech R&D, a dangerous approach that risks a backlash. Estée Lauder, for example, reportedly held a special meeting earlier this year, instructing employees never to use the “nana” prefix.

Finally, start-ups even struggle to obtain business services. We have heard direct reports of one U.S. insurer cancelling coverage of small companies once it learned that they were involved with nanotech.

This committee has asked what the priority areas of research should be. We don’t see identification of priority areas as being the key roadblock to progress. Multiple well developed needs lists have already been produced by organizations ranging from the EPA to the Wilson Center and, most recently, NEHI. They all prioritize the development of test methods, hazard screening, and exposure route investigation.

What is missing is not this ingredients list, but two things: a specific game plan for accomplishing the research, and adequate funding to execute it.

The biggest issue is the absence of a game plan. Nanotechnology EHS research in government agencies, academic institutions, and industrial facilities is being performed in an ad hoc fashion, according to individual priorities. The NEHI Working Group has not yet established a research strategy, one that makes tough decisions about prioritizing specific research tasks, apportioning them to public and private sector entities, and measuring progress.

Now this is not surprising, because NEHI has no authority to mandate such priorities, and it can’t allocate funding. A new inter-agency body with such authority is required to break the deadlock. We believe the effort to establish one and formalize a clear, short-term research plan should be led by the National Academy’s Board of Environmental Studies in Toxicology and the National Institute of Environmental and Health Sciences.

The second issue is funding. We continue to believe that the appropriate funding level for these risks is likely between \$100 million and \$200 million annually, or two to four times today’s spending. This is not an arbitrary figure. It represents a consensus widely held in industry and among non-governmental organizations formed by bottom-up calculation, analogy to other materials, and calculations that figure the costs as an insurance premium for nanotech.

Nanotech continues to move forward rapidly in the United States. Just in the last three months, free scale semiconductors shipped pioneering nano-enabled memory chips. Becton-Dickinson partnered to create new nano-enabled diagnostics that will revolutionize disease testing.

The United States has faced new EHS issues from previous broad technology waves, like semiconductors and polymers, in the past and addressed them effectively. The same can be done in nanotech.

Thank you for inviting me to speak, and I am pleased to answer any questions.

[The prepared statement of Mr. Nordan follows:]

PREPARED STATEMENT OF MATTHEW M. NORDAN

Global sales of products incorporating nanotechnology are more than doubling annually, but environmental, health, and safety (EHS) risks threaten to stall commercialization. Industry sees three key concerns: Real risks, perceptual risks, and regulatory risks. Awareness among the scientific community is already in place and multiple, well-developed lists of research needs are already built. Now, the Federal Government must establish a game plan for basic research—which will require a new interagency body with the authority to implement that plan—and supply adequate funding to carry it out. These actions will enable companies to carry out their own research on specific applications, and help address perceptual and regulatory risks in the bargain.

Nanotech EHS Issues Still Confront Industry

Since the House Committee on Science last held hearings about the environmental, health, and safety (EHS) risks of nanotechnology in November 2005, the debate about whether and how nanoparticles might injure workers, harm consumers, or damage the environment has intensified.¹ Nanotech's growing commercial success—\$32 billion in products incorporating nanotech were sold in 2005—has meant increased scrutiny of EHS issues from advocacy groups and regulators, and increased urgency among companies developing products that incorporate nanoparticles (see Figure 1).² Lux Research studies the commercialization of nanotechnology and advises companies about how they should approach nanotech opportunities, and when it comes to EHS issues, we see three key concerns faced by industry (see Figure 2):³

- **Real risks of nanoparticles.** Companies working with nanoparticles—like metal nanopowders, carbon nanotubes, and quantum dots—need to ensure that their materials and applications won't harm people or the environment. But considerable uncertainty surrounds real risk because the hazards of most nanoparticles are not well understood, exposure can be difficult to predict and measure, and even solid scientific studies arrive at contradictory results. For example, researchers at Rice University's Center for Biological and Environmental Nanotechnology found that even at low concentrations, fullerenes are toxic to bacteria and human cells in water; however, others at the Université Paris XI found the same particles not only safe but beneficial, protecting lab rats' livers from damage caused by other chemicals.⁴ While scientists debate, companies like General Electric must forge ahead *now* with decisions about how to invest in nanotech R&D, partnerships, and products.
- **Perceptual risks when real dangers are unknown or misunderstood.** Regardless of the real risks presented by any given nanoparticle or application, firms developing products using nanoparticles could find commercial feasibility blocked by the *perception* that the materials are dangerous—even if they are proven safe. Public perception of nanotechnology in the U.S. remains largely undetermined to date, with public opinion surveys continuing to show

¹ See the May 2005 Lux Research report "A Prudent Approach to Nanotech Environmental, Health, and Safety Risks," the November 17, 2005 Lux Research written congressional testimony "Nanotech Environmental, Health, and Safety Risks: Action Needed," and the May 2006 Lux Research report "Taking Action on Nanotech Environmental, Health, and Safety Risks."

² For more information on the value of products sold incorporating emerging nanotechnology, see the February 2006 Lux Research report "How Industry Leaders Organize for Nanotech Innovation."

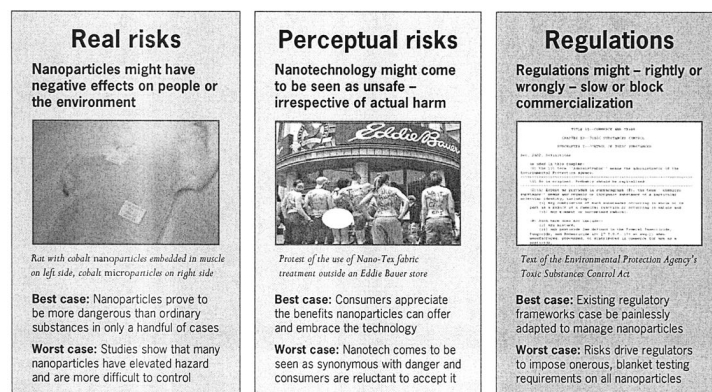
³ This testimony focuses on a specific class of nanomaterials, namely nanoparticles—purposefully engineered bits of matter size-dependent properties and sub-100 nm dimensions. They may either be miniature chunks of established materials (like Nanophase's nanoscale zinc oxide, used in sunscreens), or highly ordered structures that only form at the nanoscale (like CarboLex's single-walled carbon nanotubes, which may be soon used in flat-panel displays). We specifically do not address bulk materials with nanostructured features (like Apollo Diamond's nanostructured synthetic diamond) or nanoporous materials that have nano-sized holes (like Argonide's nanoporous ceramic water filtration media) because these materials appear unlikely on current evidence to pose novel EHS risks. We also do not address "incidental nanoparticles" which have nanoscale dimensions but have not been purposefully engineered, like the ultra-fine carbon particles emitted in diesel exhaust. It's important to note that "nanotechnology does not equal nanoparticles" and that many nanotech applications, like a wide variety of next-generation semiconductor technologies, do not involve the use of any nanoparticles at all.

⁴ "[60]Fullerene is a Powerful Antioxidant in Vivo with No Acute or Subacute Toxicity." Gharbi, N.; Pressac, M.; Hadchouel, M.; Szwarc, H.; Wilson, S.R.; Moussa, F. *Nano Letters* 2005, 5, 2578–85, and "The Differential Cytotoxicity of Water-Soluble Fullerenes." Sayes, C.M.; Fortner, J.D.; Guo, W.; Lyon, D.; Boyd, A.M.; Ausman, K.D.; Tao, Y.J.; Sitharaman, B.; Wilson, L.J.; Hughes, J.B.; West, J.L.; Colvin, V.L. *Nano Letters* 2004, 4, 1881–1887.

low awareness of nanotechnology and high optimism. A 2005 U.S. study found that just 16 percent of respondents rated themselves “at least somewhat informed” about nanotech, but in the same study 66 percent agreed with positive statements about the field.⁵

However, many non-governmental organizations opposed to nanotech development—particularly those overseas—have grown more forceful in their protests. In May 2006, the environmental group Friends of the Earth issued a fiery report on the use of nanoparticles in cosmetics and sunscreens, condemning companies for “treating their customers like guinea pigs” and calling for a ban on the use of nanomaterials in these products. When the French government’s Minatec nanotechnology research center opened in May 2006, protestors stormed conference rooms and accosted scientists on the street. Such reactions make firms like Johnson & Johnson look at the decades-long public relations and legal battles over supposedly dangerous products, from silicone breast implants to red M&Ms, and wonder whether even the safest nanoparticles could become a liability.

Fig. 2: Industry’s Nanotechnology EHS Concerns Fall into Three Categories



- **Regulations—or lack thereof.** U.S. companies will also have to abide by regulations of nano-enabled products and processes, ranging from workplace guidelines under the Occupational Health and Safety Administration to restrictions on the release of materials by the Environmental Protection Agency (EPA)—as well as regulations in the other countries where they do business.

The EPA held a public meeting in June 2005 to solicit comments on a proposed voluntary pilot program that would collect data on nanomaterials. In December it issued a regulatory decision on carbon nanotubes, the first nanoparticle submitted to it under the Toxic Substances Control Act, approving the material for manufacturing under a low release and exposure exemption; the EPA also issued a broad draft white paper on nanotechnology in the same month. Meanwhile, the Food and Drug Administration (FDA), National Institute for Occupational Safety and Health, and Consumer Product Safety Commission have all issued position papers on nanotechnology. The FDA has also gone further, announcing the formation of an internal task force and calling public meetings on nanotech.

Despite all the action, regulatory ambiguity persists—it’s still often not clear how current regulations apply to nanoparticles or whether and when agencies will issue new ones—leaving firms that work with nanoparticles confused about how to plan for regulatory rulings. While companies are generally pleased about how the EPA, for example, has communicated with them so far, they’re also frustrated by how slow those agencies have been to set spe-

⁵ “The public and nanotechnology: How citizens make sense of emerging technologies.” Scheufele, D.A., Lewenstein, B.V. *J. Nanoparticle Res.* 2005, 7, 659–667.

cific guidance, like the EPA's long-proposed voluntary Stewardship Program for nanoparticles.

With nanotech continuing to shift more and more from "R" to "D" and into products—\$150 billion worth of nano-enabled products will be sold by 2008—sound policy to help firms manage these risks effectively is more urgent than ever.

EHS Risks Are a Gating Factor for U.S. Nanotechnology Leadership

Our firm conducts hundreds of interviews, site visits, and advisory sessions each year with executives and scientists responsible for nanotech at large corporations, as well as leaders of startups specializing in nanotech. Our conversations with them rarely fail to touch on EHS issues. We hear that even as many U.S. corporations and start-ups drive nanotech commercialization forward, others are canceling their efforts or failing to find funding and support for them due to EHS risks.

- **The sheer cost of real risk dissuades companies from worthy endeavors.** Without the data, tools, and frameworks needed to manage the real risks of nanoparticles, large corporations retrench rather than expose themselves to undue liability or sink millions into toxicity tests. Meanwhile, nanotech start-ups face an even tougher situation—they have little hope of funding such research on their own, yet their customers expect them, like any other supplier, to come equipped with data on health effects. Interviewees consistently cite nanoparticle EHS concerns as a major topic of discussion, and even a bargaining chip, in partnership negotiations.

"We've stopped development where costs were too high to ensure no exposure or risk across the life cycle, or where we couldn't clearly judge hazard potential due to the lack of accepted methods. It's quite complicated; we can't set decision points today." (Corporation)

"The BASFs, Degussas, and DuPonts of the world come in with their act together, but start-ups typically say, 'Oh, we didn't bring the EHS guy with us.' We've canceled several projects because of a lack of EHS information from the supplier. We could generate the information ourselves, but it's just not worth it." (Corporation)

- **Perceptual risks threaten to drive "nano" underground.** Companies are universally concerned about perceptual risks but don't know how to handle them, and many try to duck the issue by simply forbidding the term "nanotechnology"—a dangerous strategy that risks a backlash. Executives at Estée Lauder reportedly held a special meeting in early 2006 to instruct employees, brand managers, and customer relations people to cease any use of or reference to the term. Solar-cell maker Konarka takes pains never to mention the fullerenes it uses in its flexible photovoltaics, lest EHS fears about fullerenes damage the "clean and green" message it emphasizes to investors and the public. Even companies that are comfortable with the real risks of their materials don't trust their buyers to make informed decisions about them:

"We promote the benefits better products bring without talking about technology. With nanotech, it's no different: You won't hear us talking about nanotech or advertising it in any way. That's our strategy for dealing with potential negative publicity." (Corporation)

"Our strategy is pretty clear. Focus on features and benefits; give the products names associated with benefit of product; don't put 'nano' in the name of the product." (Start-up)

- **Corporations are eager for regulation; among start-ups, paranoia reigns.** Contrary to what one might expect, large corporations consistently want to see clear regulatory guidance on nanoparticles, which they feel will ensure a level playing field and tell them what to plan for. These firms are enthusiastic about the EPA's approach—which lets them participate in its deliberations and gain insight into its thought processes—but frustrated by agencies like the FDA that have communicated less on key issues. With start-ups, on the other hand, we frequently hear the plea for "rational" and "science-based" regulations—subtext for fears that regulators will overreach and impose sweeping and onerous rules that could kill their businesses.

"Our CEO decided it was too early to make any more investments in nanotech until the FDA makes some decisions on how it will be handled. We're all very disappointed about this, since we have already dedicated significant resources." (Corporation)

"For some of our product categories, a full battery of tests might cost \$40 million. But if it's a reformulation of an existing compound, it could be only a few hundred thousand. Right now with nano we have no idea which it will be."(Corporation)

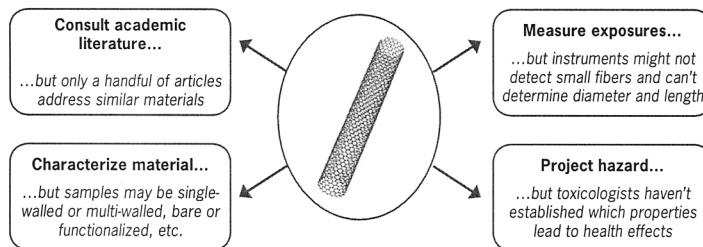
"We're working very hard to make sure regulations are in place. Everyone benefits from strong, robust regulations—not only to protect consumers, but to level the playing field for companies, so that everyone puts the right amount of thought into protecting health and assessing safety." (Corporation)

"I'm concerned about the regulatory environment. We need (real risk data), or we'll get regulated to levels that don't make sense in terms of facts. Our concern is that regulations will change not based on fact, but based on hysteria. . . hopefully the regulators won't do something silly." (Start-up)

"I have no idea how (regulation) is going to evolve. It could be very factual and science-based, or it could be very politicized. We'd like to influence it and have it be rational." (Start-up)

The combination of the struggles firms face around all three factors is leading to adverse consequences for industry and the U.S. economy, as promising innovations get de-prioritized in corporate R&D budgets for reasons unrelated to performance, price, and market demand. The results can be particularly dire for the small firms that our technologically-driven economy relies on to develop crucial innovations. Venture capitalists are beginning to shrink from funding start-ups that face nanotech EHS risks, as prominent U.S. nanotech investor Steve Jurvetson stated in a recent *Nature* article.⁶ Start-ups even struggle to obtain business services: At least one U.S. insurer has canceled coverage of small companies once it learned they were involved with nanotech.

Fig. 3: Lack of Specific Data Makes it Difficult to Apply Risk Management Techniques to Nanotech



Government Support for Basic Research Will Help Address Real Risks

Clearly the first and most important responsibility of any company developing nanoparticle applications is to ensure that they won't present hazard to workers, consumers, or the environment. As we have described previously, conventional risk management paradigms—identifying hazard, characterizing hazard, assessing exposure, and characterizing risk—can be applied to nanoparticles, and only applications where both hazard and exposure are present constitute serious risks.⁷ However, many aspects of nanoparticles make them uniquely challenging to address (see Figure 3). These challenges boil down to two key categories of research needs:

- 1) **Lack of specific data.** Simply put, the health and environmental effects of nanoparticles haven't been studied well enough for EHS professionals to assess them confidently. While a vast literature on conventional materials exists for these researchers to draw on, the literature on nanoparticles still lags behind by a wide margin. A scientist working with an organic chemical can very likely turn to the literature and find several papers addressing the health effects the compound she is studying, or at least very similar ones; scientists working with nanoparticles have no such luxury. Of 81,334 peer-reviewed journal articles on toxicology from January 2000 through May

⁶"Nanotech's big issue." Gewin, V., *Nature* 2006, 443, 137.

⁷See the May 2005 Lux Research report "A Prudent Approach to Nanotech Environmental, Health, and Safety Risks" and the November 17, 2005 Lux Research written congressional testimony "Nanotech Environmental, Health, and Safety Risks: Action Needed."

2006, just 0.6 percent make any mention of nanoparticles—compared with 12 percent for polymers, a much better-known class of materials.⁸ More specifically, we identified just 316 articles specifically focused on the EHS risks of engineered nanoparticles (through May 2006) from a review of over 1,500 documents drawn from databases of published research like that maintained by the International Council on Nanotechnology (ICON) at Rice University, literature searches using Science Citation Index; and review articles like the report from the International Life Sciences Institute Nanomaterial Toxicity Screening Working Group.⁹

- 2) **Lack of well-developed frameworks for understanding real risks.** For more familiar classes of chemicals and materials, long experience has given scientists a good understanding of what characteristics make a substance harmful, so they can make reasonable judgments even when they lack specific toxicity data. In the case of nanoparticles, however, these frameworks (often referred to as “structure-activity relationships”) are only beginning to be developed, and current results often contradict each other. For instance, while Günter Oberdörster at Rochester University found that smaller particles of titanium dioxide (TiO₂) are more harmful than large ones, David Warheit at DuPont found no relationship between size and toxicity; he also found that nanoparticles of silica (SiO₂) and zinc oxide (ZnO) are *less* harmful than larger ones.¹⁰

Nanotech’s critics rightly point out that companies themselves must take responsibility for generating data on the specific materials they work with and applications they put the materials to, and shouldn’t depend on the government to do it for them. This important point addresses the first category of research need above.¹¹ However, the key role for government lies in the second category of research need: Supporting the basic research needed to develop *frameworks* that companies and researchers can put to use in evaluating their own materials. Just as wise government funding produced the fundamental scientific breakthroughs that lead to the *successful* nanotech commercialization we’re seeing today, similar investment in under-

⁸ Science Citation Index as of May 21, 2005; search terms “(toxic* OR toxico*) AND (X)”, where X = (quantum dot OR nanopartic* OR nanotub* OR fulleren* OR nanomaterial* OR nanofib* OR nanotech* OR nanocryst* OR nanocomposit* OR dendrimer*) or X = (poly* OR copoly* ANDNOT polychlorinated).

⁹ The ICON database can be found at http://icon.rice.edu/centersandinst/icon/resources.cfm?doc_id=8597. The ILSI report was published as “Principles for characterizing the potential human health effects from exposure to nanomaterials: elements of a screening strategy” Oberdörster, G.; et al. *Particle and Fibre Toxicology* 2005, 2:8. Other review article used were: (a) “Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultra-fine Particles.” Oberdörster, G.; Oberdörster, E.; Oberdörster, J.; *Env. Health Perspect.* 2005, 113, 823–839. (b) “Airborne nanostructured particles and occupational health.” Maynard, A.D.; Kuempel, E.D. *J. Nanoparticle Res.* 2005, 7, 587–614. (c) “Industrial application of nanomaterials—chances and risks.” Luther, W., ed. Future Technologies Division, VDI Technologiezentrum (sponsored by the EC Nanosafe program). With over 1300 records in the ICON database, readers may be surprised that so few are used in our analysis. ICON’s database includes many articles on incidentally-produced nanoparticles (such as those found in diesel exhaust or generated by welding), as well as articles on environmental or health applications of nanomaterials, such as the use of iron nanoparticles in wastewater remediation or polymer nanoparticles in drug delivery. Such studies can contain helpful information on hazard or exposure, but are of less direct use for trying to understand the risks of their own materials than those that squarely address EHS questions.

¹⁰ Oberdörster, G.; Ferin, J.; Lehnert, B.E. *Environ. Health Perspect.* 1994, 102, Supplement 5, 173–179; “Pulmonary Instillation Studies with Nanoscale TiO₂ Rods and Dots in Rats: Toxicity Is Not Dependent upon Particle Size and Surface Area.” Warheit, D.B.; Webb, T.R.; Sayes, C.M.; Colvin, V.L.; Reed, K.L. *Toxicol. Sci.* 2006, 91, 227–236; Warheit, D.B., personal communication.

¹¹ A key exception to this rule lies with start-up companies. As we have previously stated to the House Committee on Science, start-ups are both generally the earliest commercial developers of new nanoparticles and also the parties least likely to be able to afford expensive toxicology studies. As long as these dynamics hold, there will be a market failure that only government can correct. We continue to believe that a market-based mechanism, which would require companies receiving government funding for products that incorporate nanoparticles to submit their materials for anonymous testing as a condition of the grant, is the most efficient way to ensure that scarce government research funds are allocated efficiently to materials of greatest commercial interest. Such a mechanism would place a new requirement on small businesses receiving Small Business Innovation Research and/or Small Business Technology Transfer grants, but because the only requirement is the submission of a small amount of material for anonymous testing with no financial or onerous documentation requirements, it does not seem to our layman’s eyes to represent an undue burden.

standing the basic science of nanoparticle EHS factors will underlie *safe* nanotech developments.

Research Priorities Are Well-Understood; What's Needed Is a Game Plan and Money

In terms of specific research needs, we do not see identification of priority areas of research as being the key roadblock to progress. Multiple well-developed needs lists have already been produced by organizations ranging from the EPA to the Wilson Center, and they all prioritize the development of test methods, hazard screening, and exposure route investigation (see Figure 4). What is missing is not this “ingredients list,” but two things: A specific game plan for accomplishing the research and adequate funding to execute it.

- **A new interagency body must form a nanotech EHS game plan—with authority to execute.** The biggest issue is the absence of a game plan; nanotechnology EHS research in government agencies, academic institutions, and industrial facilities is expanding, but it is being performed in an ad hoc fashion according to individual priorities that both risk costly duplication of effort and raise the specter of key issues remaining unaddressed. The National Science and Technology Council's Nanotechnology Environmental and Health Implications working group (NEHI), the body nominally in charge of nanotech EHS issues as part of the National Nanotechnology Initiative (NNI), has not yet established a research *strategy*—one that makes the tough decisions about prioritizing specific research tasks, apportioning them to public and private sector entities, and measuring progress. This is not surprising, because NEHI has no authority to mandate such priorities and cannot allocate funding. A new, interagency body with such authority is required to break the deadlock. The effort to establish such an authority and formalize a clear, short-term research plan could be led by NEHI, but also the National Academies' Board on Environmental Studies and Toxicology or the National Institute of Environmental Health Sciences.
- **Funding must grow.** We continue to believe that the appropriate funding level for addressing nanotech EHS research needs is likely between \$100 and \$200 million annually, or two to four times today's spending under the NNI. This figure is not an arbitrary number, but represents a consensus widely held in industry and among non-governmental organizations formed by bottom-up calculations, analogy to other materials, and calculations that figure the costs as an “insurance premium” for nanotech development.

Fig. 4: More than Half a Dozen Well-Developed Lists of Nanotech EHS Research Needs Exist Now

Group	Date	Document	Available at:
European Commission (EC)	June 2005	Nanosciences and nanotechnologies: An action plan for Europe 2005-2009	cordis.europa.eu/nanotechnology/actionplan.htm
U.S. National Institute for Occupational Safety and Health (NIOSH)	September 2005	Strategic Plan for NIOSH Nanotechnology Research	www.cdc.gov/niosh/topics/nanotech/strat_plan.html
Consortium of researchers	October 2005	Principles for Characterizing the Potential Human Health Effects from Exposure to Nanomaterials: Elements of a Screening Strategy	http://www.particleandfibretoxicology.com/content/2/1/8
U.S. Environmental Protection Agency (EPA)	December 2005	External review draft of nanotechnology white paper	www.epa.gov/osa/nanotech.htm
U.K. Department for Environment, Food and Rural Affairs (DEFRA)	December 2005	Characterizing the risks posed by engineered nanoparticles: A first UK Government research report	www.defra.gov.uk/environment/nanotech/nrcg/pdf/nanoparticles-riskreport.pdf
EC Scientific Committee on Emerging and Newly-Identified Health Risks	March 2006	Opinion on the appropriateness of existing methodologies to assess the potential risks associated with engineered and adventitious products of nanotechnologies	ec.europa.eu/health/ph_risk/committees/04_scenhr/docs/scenhr_o_003b.pdf
Woodrow Wilson International Center for Scholars	July 2006	Nanotechnology: A Research Strategy for Addressing Risk	http://www.nanotechproject.org/file_download/77

Towards these ends, Lux Research has joined with a broad consortium of nanotech stakeholders, including leading corporations active in nanotech (like Air Products & Chemicals, BASF, Degussa, and DuPont), non-governmental organizations (like Environmental Defense, the Natural Resources Defense Council, and the

Union of Concerned Scientists), prominent nanotech start-ups (like Altair Nanotechnologies and Carbon Nanotechnologies Inc.), and business associations (like the NanoBusiness Alliance). This coalition has petitioned the Senate Committee on Appropriations both to increase funding for nanotech EHS research, and to allocate \$1 million to the National Institute of Environmental Health Sciences and the National Academy of Sciences to develop a specific game plan for the U.S. Government's approach to nanotech EHS research. We encourage Committee members to support these efforts.

Better Research on Real Risks Will Help Address Perceptual and Regulatory Ones

There is less that Congress can do to aid with perceptual risks, and while regulation clearly falls into the Federal Government's remit, key decisions need to be made at regulatory agencies. However, successfully addressing the basic research needs around real risks will help make significant progress on these challenges as well. Consider that:

- **Better understanding will drive regulation.** Regulatory transparency is important for nanotech's commercial development, but agencies are hesitant to issue specific guidance, even on general principles, without a better scientific understanding of the issues involved. While we still think agencies can do more to communicate their thinking to industry and to set specific regulatory expectations in a timely fashion, the basic research spurred by additional investments and research prioritization alone will help them set firm plans.
- **Lack of knowledge—and of regulations—are major drivers of perceptual risks.** One of the most significant “fright factors” identified for new technologies is “poor understanding by science or responsible agencies,” which certainly describes nanotech today.¹² Moreover, arguments that nanotech is unregulated are widely used by groups calling for restrictions on development. By addressing this lack of understanding and abetting regulatory efforts, Congress can help promote informed public understanding of nanotechnology's benefits and risks.

Addressing Nanotech EHS Risks Has a Big Economic Payoff

Nanotechnology continues to move forward rapidly in the U.S.—just in the last three months, Freescale Semiconductor has shipped pioneering nano-enabled memory chips, and Becton Dickinson has partnered to develop new nano-enabled medical diagnostics that could revolutionize disease testing. While we calculate that \$32 billion in nano-enabled products were sold in 2005 and project that \$150 billion will be in 2008, and that by the middle of the next decade this value will figure in the trillions of dollars globally. The U.S. has faced new EHS issues from previous broad technology waves, like semiconductors and polymers, in the past, and addressed them effectively; it's important that we do so for nanotechnology as well—since the challenges facing our country in achieving energy independence, finding curing for debilitating diseases, securing the homeland, and creating new jobs and economic growth all benefit from nanoscale science and engineering.

BIOGRAPHY FOR MATTHEW M. NORDAN

Matthew Nordan is the President of Lux Research and heads the company's research organization. Under Matthew's leadership, the Lux Research analyst team has become a globally recognized authority on the business and economic impact of nanotechnology. Lux Research serves as an indispensable advisor to corporations, start-ups, financial institutions, and governments seeking to exploit emerging technologies for competitive advantage.

Matthew has counseled decision-makers on new technologies for a decade. Prior to Lux Research, Matthew held a variety of senior management positions at emerging technology advisor Forrester Research, where he most recently headed the firm's North American consulting line of business. Earlier, Matthew lived for four years in the Netherlands growing Forrester's operations in Europe, where he launched and led research practices in retail, mobile commerce, and telecommunications.

Matthew has been invited by news outlets including CNN and CNBC to comment on emerging technology markets and has been widely cited in publications such as *The Wall Street Journal* and *The Economist*. He has delivered advice to clients and

¹²Bennett, P.; Calman, K. *Risk Communication and Public Health*. Oxford University Press, Oxford, 1999.

been an invited speaker at conferences in North America, Europe, Southeast Asia, Japan, Australia, and South Africa. Beyond the corporate sphere, Matthew has testified before the U.S. Congress twice on nanotechnology issues, advised the Committee to Review the National Nanotechnology Initiative of the National Academies, and spoken on nanotechnology at universities including Harvard, MIT, and Columbia. Matthew has also participated in developing public-sector technology strategy for organizations including the World Economic Forum, the European IT Observatory, and the Dutch transportation ministry.

Matthew is a summa cum laude graduate of Yale University, where he conducted cognitive neuroscience research on the neural pathways mediating emotion and memory.

DISCUSSION

COORDINATING FEDERAL ENVIRONMENTAL, HEALTH, AND SAFETY NANOTECHNOLOGY RESEARCH PROGRAMS

Chairman BOEHLERT. Thank you very much, Mr. Nordan.

I would point out to the government witnesses that both you and Dr. Maynard have pretty clearly and convincingly laid out the deficiencies in the current federal program. And quite honestly, if I sense things up here from this side of the witness table, I think Mr. Gordon, in his opening statement, which was very emphatic and very eloquent, he has got the mood of the Committee on both sides of the dais.

So here is what I would like to do. I would like to ask each of our witnesses what they think needs to be done to have a truly coordinated, targeted, prioritized federal program. And while you are giving some thought to that, let me point out that what—you have been at this for more than a year, and what, essentially, we have is a basic inventory. We don't have any priorities. We tell that is the "next step." I mean, I think we should be a lot farther ahead now than we are. I was a little—tried to finesse it a little bit in my opening statement, but Mr. Gordon got right to it. And I have to say, "Amen."

So let us go. You are the——

Mr. GORDON. Mr. Chairman, if I could, I think you have hit the heart of the question, and I would like to share my time with you, if these folks need the time to address, again, the fundamental question for us today.

Chairman BOEHLERT. Yeah. And so let me just repeat it.

What do you think needs to be done to have a truly coordinated, targeted, prioritized federal program?

Dr. Alderson.

Dr. ALDERSON. Thank you, Mr. Chairman.

Obviously, this is a very important question to the NEHI group and NSET as well.

My response to your question is, and I think I am speaking for all the members of the NEHI committee, we believe we are on the track to get to that point. The issue is how long will it take us to get there. All of the 19 agencies that are represented on NEHI represent the best scientists, expertise, I think, the Federal Government has to offer on this issue. Bringing them together in this environment, I believe, is the best approach to get there.

How to speed that up is another issue.

As you mentioned earlier, all of us have other jobs. This is something else we are all doing. So it is a matter of how much time do

you want us to spend on this, how much does our respective agencies want us to spend on this to make this happen. But I really, honestly believe this group is the body to do that.

Chairman BOEHLERT. Dr. Bement, look, you are right. Just let me point out that once again, as I said before, we have a high regard for each one of you. You are dedicated, very able federal employees. I don't know how many various interagency panels you are on, Dr. Alderson, for example, and Dr. Bement. I mean, it is probably as long as—the list is as long as your arm. Some—we would be comforted if we had some indication that you are giving some priority attention to this. And I understand all of your other demands in your schedule, but there is no evidence of that thus far. I would suggest that the one reason we have this report today is we sort of forced it, because we have scheduled this hearing, and your staff probably said, "We have got to get ready for those guys. They are going to ask some questions. You better show some movement." So this is what you came up with. And if this hearing hadn't been scheduled, we probably wouldn't have anything yet.

So I am not trying to be argumentative or confrontational. I just want you to sense from here that we feel very strongly about this on both sides, and we know you have the wherewithal, the commitment, and all of that. Let us hope you get some time and attention to it.

Dr. Bement.

Dr. BEMENT. Well, I will address your question from my perspective.

Chairman BOEHLERT. Yeah. And well, while you are at it, I wanted to ask, is there someone that you think should be directed to have his sole job as being chair of this coordinating agency?

Dr. BEMENT. Well, I will come to that question in a moment.

The first point I would like to make is that characterizing the current situation as a "bottom-up approach" is overstating it. It is true that it is bottom up as far as science input and the various agencies' input into the budget formulation process. But it is also lateral. There is a lot of interagency cooperation. We solicit inputs from the regulatory agencies in identifying those scientific questions that we need to address. And it is also top-down through the budget—

Chairman BOEHLERT. Well, that is very important. You know. And the top-down—what I am asking is should we get someone solely committed to coordinating this thing, or do we say to Dr. Alderson—

Dr. BEMENT. Well—

Chairman BOEHLERT.—this is the 27th item on your agenda. You have got to chair this interagency—

Dr. BEMENT. Okay. I have been in government a long time, and almost in every new program of this type, everyone wants this on top, but I have to tell you that this area is so complex that I don't know of any person or a small group of people who would be smart enough to be able to identify all of the risks, set the priorities, and lay out a so-called game plan. That has to be very organic, and it is organic. It—the situation changes day by day. And so there has to be more of a soccer approach to this rather than an American football approach, if I can put it in that metaphor.

Chairman BOEHLERT. Dr. Maynard is nodding yes.

Mr. GORDON. The Chairman graciously—we are sharing time and sharing this. We are not asking that there be somebody smart enough that knows it all. We are asking that there is somebody that is able to coordinate it all. I think there is a difference.

Dr. BEMENT. Yeah. Well, I didn't say the last thing I wanted to say, and that is how it is top-down managed. It is top-down managed through the budget—the formulation of the budget review and the budget approval process in putting together the Administration's budget to the Congress. That is a matter of policy. It is policy formulation. And that is a very well coordinated process through OMB and OSTP. So you do have two very high government offices that do provide this coordination, and it is top-down.

Mr. GORDON. So you are satisfied that we have got the best plan now or the best—

Dr. BEMENT. No, I am not satisfied. I came up through nuclear technology, and I know what happened to that industry because it wasn't visible enough. It didn't have adequate dialogue with the public at large. And they weren't forward with—they weren't as forthright as the industry needed to be about risks. We have to avoid that, and we have to be anticipatory. We have got to be proactive, and we need to turn up the gain. I have no arguments with any of that.

Chairman BOEHLERT. Yeah, but you are not satisfied with the present arrangement. I mean, won't you concede to us? I mean, I am not trying to put you in a spot, but you can't be happy with where we are right now, given the magnitude of the problem and the magnitude of the challenge.

But I—once again, Doctor, I can imagine what your schedule is like every single day, each one of you in the government. You have got more things to do than you have got time to do them. But we are suggesting that maybe someone should be, not a Czar, but at least a coordinator and have more time to devote to coordinating. I mean, how do your various departments decide how much to allocate to nanoresearch? Does OMB tell you how much you allocate? I mean, he doesn't know diddley about nanoresearch. Is it just an exercise in numbers?

Dr. BEMENT. Well, I think each agency has a process for developing priorities and also developing their request. And that has to be discussed, and it has to be prioritized. And that is, again, OMB and OSTP.

Chairman BOEHLERT. Well, let us get Dr. Farland a chance to answer the question.

Dr. FARLAND. Thank you, Mr. Chairman.

Chairman BOEHLERT. And keep in mind you have already announced that you are already retiring, so you can be a little bolder if you want to.

Dr. FARLAND. Well, I am just going to start my remarks by suggesting that both society and government really have multiple needs in understanding these health and environmental issues. And so I think to suggest that there could be a single approach that was really going to get to this without addressing those multiple needs may be a bit naive. So I think we have to look at this

from the standpoint of the complexity of the problem that we are facing.

Chairman BOEHLERT. But, Dr. Farland, let me just say, first of all, I am not a scientist, and Mr. Gordon is not a scientist. We have got some scientists, a couple of physicists on the panel, and Ralph Hall knows everything about everything. But—so we are not suggesting that it is easy. What we are saying in every way that we know how is that we think it should be given a higher priority. There should be better coordination. We think we should be farther ahead than we are now after a more than a year invested, the time and talent of several able, dedicated public officials. And what we have now is just sort of a basic inventory that was sort of forced out, you know, pulled out, extracted because the hearing was scheduled. So—

Dr. FARLAND. Well, let me try to address a few of those points, because I think that, first of all, from an agency perspective, we benefit tremendously by the kind of interagency dialogue that has gone on in the NNI and in the NEHI particularly. We play a large role in that. We share the feelings we have about the priorities. We take from others what they can do and what their priorities are.

We also take that back, and we don't wait for those priorities in terms of making decisions.

Mr. GORDON. Okay. If I could—are you satisfied with the structure, as Dr. Alderson said, to get us—he used the word “there.” I would like to know more what “there” is. But are you satisfied that we have an adequate structure to get us “there”?

Dr. FARLAND. I think we have a structure that is working very well right now. It has a way to go. I agree with that. I agree that we have—

Mr. GORDON. Okay. So how do we—you know, so what else do we need to do? To me, that is the fundamental question here we are trying to determine is whether or not we have a structure that is going to allow us to get, as Dr. Alderson said, you know, “there.” And we can talk about “there” other—I mean, but do we have that structure? And if not, how do we need to—it is not a criticism to anyone. You know.

Dr. FARLAND. Dr. Bement talked about the idea of turning up the game. And I think that is happening. It is happening as we work through these kinds of issues. It is happening as we have our dialogue, our workshops with our—

Mr. GORDON. So we have an adequate structure? There just needs to be more intensity within that structure? Is that—

Dr. FARLAND. That is the way I see it.

Mr. GORDON.—what you are—okay. All right. Thank you.

Chairman BOEHLERT. Dr. Carim.

Dr. CARIM. Yes. Thank you.

With respect to the report, honestly, we have done our best to produce a report that tries to address these issues in a way that is coordinated across the Federal Government, the federal agencies, and that is of high quality, that really produces a science-based approach to risk assessment and to what the research needs are in this area. And that takes time. It has been an ongoing effort, and I think the level of effort has been quite high. And I won't deny

the fact that certainly the presence of the upcoming hearing and the activities——

Mr. GORDON. And so are you satisfied with the——

Dr. CARIM.—have added some——

Mr. GORDON.—structure that we have?

Dr. CARIM. Yes, I am.

Mr. GORDON. Okay.

Dr. CARIM. I think——

Mr. GORDON. All right. That is fine.

Dr. CARIM. I think that having these other activities certainly added some urgency to agency responses and to agency approvals, and that is a good thing.

I would agree with the comments of my colleagues, and I do think that, with respect to a more top-down organization, you have heard some things about the top-down aspects that are already in place, but I share the Chairman's sentiment that diversity is a source of strength in the research programs of the United States. And this is already one of the most highly coordinated activities across agencies, and I am afraid that taking too much of a top-down approach will cause us to miss things. That is one of my largest concerns is that if we feel that we have identified the priority areas and addressing those——

Mr. GORDON. Could they help us be more efficient with what seems to be terribly limited funds?

Dr. CARIM. I am sorry?

Mr. GORDON. Could it help us to be more efficient with what seems to be terribly limited funds?

Dr. CARIM. Increases in efficiency are always valuable. The question is how to do that. And I think it is all of the agencies.

Mr. GORDON. Okay. But we wouldn't have as much duplication, potentially, if we had more leadership?

Dr. CARIM. I don't believe that we have much duplication.

Mr. GORDON. Okay.

Dr. CARIM. I believe that the——

Mr. GORDON. All right.

Dr. CARIM.—interagency coordination process is very effective in informing each agency as—of what the others are doing.

Chairman BOEHLERT. Thank you, Doctor.

I am anxious to get to other members of the panel. We shared this opening time, and I hope this is instructive to all of you that there is a high level of intensity in terms of our feeling on this. And before I call on Dr. Schwarz, I don't know—Dr. Maynard and Mr. Nordan are the ones that outlined the problem, so we needed the government agency to—I mean, they agree with you and with us, essentially.

It is unfortunate that somewhere someone mentioned the word "czar," because then we—it connotes a dictator is going to say, "This is what you are going to do." And that is not what we are talking about. We are talking—when we talk about someone at the top, just devotes more time and more effort to do a better job of coordinating the diverse elements coming in and helping to get what Dr. Maynard and Mr. Nordan are pleading for, some priorities and some emphasis. So we are not talking about a dictator that we want to install someplace in Washington, DC, but we are

saying that we want—and I hope it is instructed for all of you, we want something more than what we have now. We are not satisfied. We are not pointing fingers at any one individual saying, “You are not doing your job.” We are just saying the present mechanism doesn’t seem to be working in a way that would satisfy us that we are giving a sense of sufficient urgency to the issue.

With that, let me call on Dr. Schwarz.

REGULATORY STRUCTURE FOR UNIVERSITY AND INDUSTRY NANOMATERIAL RESEARCH

Mr. SCHWARZ. Thank you, Mr. Chairman.

I am randomly asking, so anyone jump in that chooses to do so.

I am a cutting doctor and not a research doctor. However, I am on the board of the Life Science Institute at the University of Michigan, which meets tomorrow, in fact, on the board of the Cardiovascular Center at the University of Michigan, on the Deans Advisory Committee for the school at that university, which supervises those activities, and I am the President of the Alumni Association of the University of Michigan, which I think all of you would say is one of the foremost research universities in the country. So I have an interest in this.

Very, very briefly, many of the new therapies, the 21st century therapies, putting an anti-cancer substance right on the tumor cells right in the affected organ, putting the material right at the correct spot in the correct coronary artery, et cetera. That is not Buck Rogers stuff anymore. That is stuff that can be done in the lab with nanomaterials. Yet there seems to be no regulatory structure right now that a place like my university or other universities—a structure that they can look to to say, “This is what we can do and this is what we can’t do.” But my question is this: what do you foresee and when do you foresee a structure, an office, an organization at the federal level, or certainly overseen by the Federal Government, that a University of Michigan or a Harvard or a Yale or a Stanford or a Cal or a Kansas or a Nebraska can look to when they do this research and say, “This has been vetted. This is okay. We can go ahead with animal research. We can even go ahead with, perhaps, clinical trials on humans.”? Who is going to be the referee here, and when is that referee going to be up and ready to make his or her calls?

Dr. ALDERSON. Thank you, Mr. Schwarz, for that question, and I think it is an excellent one, because it brings into the forefront a very significant potential use of nanomaterials. And what you are talking about is a delivery mechanism to bring therapy to cancer patients, i.e. bringing that pharmaceutical directly to that tumor or that cancer site. We are, within FDA, having frequent conversations with companies and academic institutions on this particular issue. We believe we have the structure in place today to be able to communicate with those companies that are developing these products. We have a very structured process of determining the safety, particularly—as a major concern, particularly for the nanomaterials if it is something that is normally—that is foreign to our body. But we have—I think we have that structure in place today to talk to a company who is manufacturing that and guide them through the type of information we want to see along the

process from the basic pharmaceutical information to laboratory information to determining whether it is safe enough to go to clinical trials. I think——

Mr. SCHWARZ. You——

Dr. ALDERSON. I think that we have that.

Mr. SCHWARZ. Dr. Alderson, you feel that you have guidelines in place that are reliable that legitimate researchers can pick up the phone, travel to Washington, you can have someone travel to their lab, and you have got standards in place that are reliable standards where a lab, whether it is in a university or in a private organization, can actually come to you and say, "Is this good? Is this bad? Can I do this? Can I not do this?"

Dr. ALDERSON. We have guidances in place for that type of product, and we are regularly talking with companies along those same lines you are talking about. Now we may—down the road, we may find that something we are asking for presents an issue that we haven't seen before, and we will have to work with the company in a manner to overcome that particular issue.

Mr. SCHWARZ. I am happy to hear that, because I—in my mind, I had assumed, always a dangerous thing, but I had assumed that there was—that the structure was a work-in-progress and there wasn't a good identifiable, reliable structure in place. You are telling me that there is?

Dr. ALDERSON. I think we are prepared to talk with any company who wants to talk to us about a product like that.

Mr. SCHWARZ. And any university as well?

Dr. ALDERSON. Anyone.

Mr. SCHWARZ. Thank you.

Chairman BOEHLERT. The gentleman's time has expired.

Here is the deal. There is a series of votes in the House, and we are not going to keep you here while we go over and play legislators. There will be a series of written questions that we will submit to all of you, and we would ask for timely responses.

In the time we have remaining, we are going to give a couple of minutes each, and we will run the clock down, to Mr. Green, and then is it Mr. Hall, Mr. Rohrabacher, and Mr. Honda. All right. Let us go.

Mr. Green.

IS THE MARKETPLACE OUTRUNNING RESEARCH?

Mr. GREEN. Yes, sir. Thank you, Mr. Chairman, and thank you and the Ranking Member for placing policy above politics. I will be as pithy and concise as possible.

It is my understanding, of course, that because something is nano doesn't mean that it is dangerous, per se. Nanomaterials can absorb pollutants in water. However, with hundreds of products on the market, \$32 billion in revenue, by one estimate, an estimate that by 2014 we may have \$2.6 trillion in revenues, and given that we are currently using—utilizing nanomaterials in clothing and cosmetics, the question has to become, first of all, is time on our side, given the way the marketplace is responding to this technology? And it has been said by someone that nanoparticles are like the roach motel: they check in, but they don't check out. So we

have to ask ourselves about time and are we using our time as efficaciously as possible.

So to this end, I am curious as to whether we have any products right now that contain any kind of warning with reference to the use of nanoparticles?

Yes, sir, if you would. And be as quickly as you can, because I have another question.

Dr. MAYNARD. I will just briefly answer that.

I—you are exactly right. Not every nanomaterial is going to be safe. Not every nanomaterial is going to be harmful. We have got to find out what is the truth here. We have got to have sound science.

Now if you look at what is on the marketplace at the moment, again, you are right: time is not on our side. We are having a flood of nano-based materials on the market, and I am not aware of any product which has any warnings or any identification of what any of the potential risks might be.

And while I am speaking, let me also say, going back to my statement, apparently I inadvertently credited the government with only spending \$1 million a year on risk-based research. I apologize for that. The figure should have been \$11 million a year.

Mr. GREEN. Quickly, one final question, if I may, Mr. Chairman.

We talked about warnings. Now what about notification? Is there a codified methodology by which notification can be perfected in the event we have some—well, some failure that we need to call to the public's attention in a massive way?

Mr. NORDAN. My understanding is that there is no such facility today. And I think if you look at the rare cases where there have been products that have incorporated nanoparticles or have been thought to incorporate nanoparticles where there have been health effects, it is a good demonstration. The best case study for this is a product by a company called Kleinmann in Germany called "Magic Nano," which was a spray that was used as an adhesive in bathrooms that caused about 100 people to have respiratory problems and to check into hospitals. It was actually later found that the product contained no nanoparticles at all. But if you imagine, particularly from the perspective of someone like the—

Mr. GREEN. Thank you, Mr. Chairman.

Chairman BOEHLERT. Mr. Honda.

And incidentally, we are trying to be mindful of your schedules. You know. You don't want to sit around and wait for us. And you are busy. We want you to go back to work on this in urgency.

Mr. Honda.

SETTING PRIORITIES

Mr. HONDA. Thank you. Thank you, Mr. Chair.

And I just—what I have surmised is that we have folks who say, "This is adequate." And then we have this that tells us what is not adequate in this, and it sets up a timeline.

My question is have you read this document as of yet, Mr. Alderson—Dr. Alderson? The question is have you read this as of yet?

Dr. ALDERSON. Yes, sir, I have.

Mr. HONDA. And how do you see this fitting in this report?

Dr. ALDERSON. They are both very consistent in terms of a focus of the research programs. Neither are that detailed in specific studies that I think we ultimately want to get to in terms of programs. The report you have in your hand there does give some areas in what should come first. And that may be correct. But I think the government, a little, has not done an assessment of that where it would either concur or not concur.

Mr. HONDA. How long would it take you to decide whether you need to take the first step or not?

Dr. ALDERSON. I could not give you an estimate of that, sir.

Mr. HONDA. Could you take a week and get back to me on this?

Dr. ALDERSON. Yes, sir.

Mr. HONDA. Thank you.

Chairman BOEHLERT. All set?

Mr. Lipinski.

PUBLIC AWARENESS OF NANOTECHNOLOGY

Mr. LIPINSKI. Thank you, Mr. Chairman.

A lot of things to talk about here, but I will keep it very short. I would also want to make clear that I believe we need to move forward. We are not moving forward quickly enough.

And now moving forward to reading this report, I have not had a chance to read it yet, but it is critical, in this new technology, that we set the—what we need to let the people know, people have confidence in it, those in the general public and also those who are involved in nanotechnology know where we are going.

At another time, I would like to talk to Dr. Bement about what NSF is doing. I know NSF is doing a lot of funding of research in nanotech. At my alma mater, we have the center for nanofabrication and molecular self-assembly. I would like to talk to him at some other time if he thinks everything is going well with NSF funding for nanotech.

But what my question boils down to is does anyone on the panel have any opinions on a sense among the general public about—do you have any clue what nanotech is and the impact that it may have on them? And someone had raised earlier, when I was watching this, that the public needs to be comfortable with nanotech. Is this a problem that we have seen yet?

Dr. Maynard.

Dr. MAYNARD. Very briefly, earlier this week, we released the results of a poll of public opinions. This was a telephone poll of over 1,000 people across America, and we found some very interesting things. We found that there is still a low level of awareness of nanotechnology. Overall, it was about 30 percent of the people polled that heard something about it, although this figure is up from the previous poll two years ago by about twice the number of people. So people are beginning to get aware of this.

People are also beginning to become aware of the debate over the benefits versus the risks. One of the messages not only in that but in also talking to people, we are finding that people want information of what is happening with this technology. They want to know where it is going to impact on their lives, what the benefits are, what the risks might be so that they can plan accordingly. At the

moment, people are pretty ambivalent about whether it is good or bad. They want information.

Mr. LIPINSKI. Dr. Bement, do you have something you want to add?

Chairman BOEHLERT. And you will have the final word.

Dr. BEMENT. I will have the final word.

NSF is one of the promoters of nanotechnology. Also recognize at the very beginning of the National Nanotechnology Initiative, that it was critically important not only to look at the environmental and health safety aspects but also public outreach and education. And so we have a balanced program in that regard. But we started out with a huge agenda in this area. First of all, we had to do the basic research, and if I can take a little bit out of Dr. Maynard's written testimony, he calls for systematic scientific research to recognize potential risks at an early stage. He recognizes that nanotechnology is complex. And we have to look longer-term to identify emerging risks.

But in addition to that, we had to put an infrastructure in place. We even had to develop characterization tools so that you could even look at nanoparticles and understand it in terms of their size, their shape, their surface charge, their physical and chemical characteristics of nanoparticles, and not all of those tools are yet developed.

Furthermore, and finally, we had to develop a workforce, a science and engineering workforce that not only could do the research but could also look at toxicology, could look at interaction with cells, could look at the various transport modes, and that workforce is now migrating into academia, in the National Laboratories, and also in the federal laboratories.

Chairman BOEHLERT. Thank you, Doctor.

That is it.

We have got less than five minutes to report, and we are considerate of your time, and so we could say we recess, but we are going to adjourn and—with this request: we will submit questions in writing, and we would appreciate a timely response. A timely response. And I would indicate that you get back before Dr. Farland and I go off into the sunset. The last time we submitted written questions, it took four and one-half months for the Administration to get the okay to get us answers. That is not "timely response." So I am anxious to pursue this before I leave.

And secondly, Mr. Gordon rightfully points out that at the conclusion of the report, you talk about the "next steps." Dr. Alderson, do you have sort of a timetable in mind for the "next steps"? And keep in mind—

Dr. ALDERSON. Well, I think—Mr. Chairman, I think your message is loud and clear.

Chairman BOEHLERT. Thank you.

All right. With that, adjourned.

[Whereupon, at 11:30 a.m., the Committee was adjourned.]

Appendix 1:

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Norris E. Alderson, Chair, Nanotechnology, Environmental, and Health Implications Working Group; Associate Commissioner for Science, Food and Drug Administration

Questions submitted by Chairman Sherwood L. Boehlert

Q1. The Nanotechnology Environment and Health Implications (NEHI) working group report released on September 21, 2006 says that NEHI's next steps include assessing the existing portfolio of research on environmental and safety impacts of nanotechnology, identifying gaps, and setting research priorities. When will these activities begin and when do you expect them to be completed?

A1. The Nanotechnology Environmental and Health Implications Working Group (NEHI) will begin work immediately to address the "next steps" identified in the "Environmental, Health, and Safety Research Needs for Engineered Nanoscale Materials" (EHS) report. NEHI is comprised of representatives from the sixteen Federal Government agencies that are the most experienced and scientifically qualified in the U.S. Government to consider nanotechnology issues. They all recognize the importance of completing this effort as part of the United States' commitment to realizing the benefits of nanotechnology in a manner that is responsible and that protects health and the environment.

An important next step is development of a more detailed inventory of the research currently being conducted by the National Nanotechnology Initiative (NNI) funded agencies. This will involve working through the Office of Management and Budget (OMB) to get information so that we can make assessments as to the extent that current research is addressing the priority work of the five research areas identified in the research needs report.

As for a completion date, NEHI will be in a better position to define this following our receipt and assessment of the information on the current research programs funded under the NNI. We see ourselves moving expeditiously to address the issues and produce a report that is credible and endorsed by all the U.S. Government's agencies represented in NEHI. In the meantime, research related to all five research areas is continuing to be supported in increasing amounts by NNI agencies, including the Environmental Protection Agency (EPA), the National Science Foundation (NSF), the National Institute for Occupational Safety and Health (NIOSH), the National Institutes of Health (NIH), the Department of Defense (DOD), and the Department of Energy (DOE).

We understand the importance of this issue to the Committee and to the United States maintaining its dominance in the development of nanotechnology that is safe for both the U.S. consumer and the environment. We believe that the process we are following will enable achievement of these goals.

Q2. In your written testimony, you say that the NEHI working group "will only serve in an advisory capacity" with respect to setting priorities for research on environmental and safety impacts of nanotechnology. In the Q&A during the hearing, Dr. Bement said that the role of setting budget priorities is for the Office of Science and Technology Policy and the Office of Management and Budget. Does the NEHI have any role in the budget setting process of individual agencies or the White House Office's of Science and Technology Policy or Management and Budget? If so, how? If not, should it?

A2. NEHI plays a valuable role in the budget-setting process of those agencies that fund nanotechnology Research and Development (R&D). Through the interagency process, reports like the research needs document represent the consensus of all NEHI member agencies, including those that do not have nanotechnology R&D budgets, and both the Office of Science and Technology Policy (OSTP) and OMB. The work of NEHI provides input to the NNI agencies that fund nanotechnology R&D and through the development of these documents, informs and provides guidance to the respective budget formulation processes for each agency. It is through this process that the NNI agencies that do not have nanotechnology R&D funding, yet that have a mission interest, have an impact on those agencies that have nanotechnology R&D funding. In addition, the NEHI process provides for the development of mutual decisions on the direction of EHS funding in the budget setting process involving the individual agencies and OMB.

Q3. In Dr. Maynard's testimony, he reported that the Federal Government is spending less on research on environmental and safety issues than the Federal Government claims it is spending. Why do his estimates differ so greatly from the

figures reported by the Administration? What do you need to do to reconcile your figures with his? Are detailed accountings of the each agency's spending estimates available? If so, would you please provide them to the Committee?

A3. The funding amounts reported in the NNI Supplement to the President's 2006 and 2007 Budgets for spending on the environmental health and safety (EHS) research to understand the implications of engineered nanoscale materials were obtained from the Office of Management and Budget. Considerable care was exercised by OMB to obtain the best funding numbers from those agencies funding research on this topic. The intentionally restrictive definition developed by the involved agencies and used by OMB was chosen to aid program managers in making clear decisions about which projects and efforts to include in their funding estimates. The definition used by OMB in their request to the agencies was:

Research and development on the environmental, health, and safety (EHS) implications of nanotechnology includes efforts whose primary purpose is to understand and address potential risks to health and to the environment posed by this technology. Potential risks encompass those resulting from human, animal, or environmental exposure to nanoproducts—here defined as engineered nanoscale materials, nanostructured materials, or nanotechnology-based devices, and their byproducts.

With such a restrictive definition, it is doubtful that the Federal Government estimates of funding for this research topic are overestimates. In fact, the research topics being proposed by other countries for inclusion under EHS research on nanotechnology include several types of research not included in the definition given above. A key example is research to develop instrumentation and metrology for characterizing the properties of engineered nanoscale materials. Most researchers in this field now recognize that knowledge of the purity of materials used in EHS studies is key to obtaining reproducible results among research studies.

Dr. Maynard's estimates for the Federal Government's spending on EHS R&D likely differ from the Federal Government's estimates because he did not have full access to funding data from all the agencies involved in this research, and he apparently does not agree with the definition used by the Federal Government.

A detailed breakdown—beyond the agency-by-agency data provided in the NNI Supplements to the President's Budgets—of the estimated funding for EHS R&D is not available at this time. As indicated in the "Environmental, Health, and Safety Research Needs for Engineered Nanoscale materials" document, development of a more detailed breakdown of each agency's spending estimates is part of the next steps to be taken by the Federal Government as we move forward with our assessment of the research needs in this R&D area.

Q4. *In his testimony at the hearing on September 21, Dr. Andrew Maynard from the Wilson Center recommended that the government should ask the Board on Environmental Studies and Toxicology of the National Academies of Science to help develop a long-term research agenda and conduct rolling reviews for nanotechnology environmental and safety research. Dr. Maynard also recommended that the government should contract with the Health Effects Institute to manage and/or perform some of the highest priority research. What is your view of Dr. Maynard's recommendations?*

A4. The National Academies of Science (NAS) is already tasked to provide a rolling review of the NNI. It would be appropriate to ask the NAS to include the other NAS Boards in the triennial review of NNI. As for the involvement of a third party organization such as Health Effects Institute to conduct nanotechnology health and environment research, this can be an effective means to address specific needs when there is a commitment by both industry and government to provide sustained funding. Without this commitment, it can become unproductive. We are not aware of a nanotechnology industry group that can provide the sustained funding necessary to support this research.

Questions submitted by Representative Bart Gordon

Q1. *The EMS research needs report released at the hearing includes several "next steps" (page 10 of the report) for the NEHI working group. What is the estimated timeframe or developing the specific EMS research priorities, evaluating in detail the current federal EMS research portfolio, and performing a gap analysis of current EHS research compared to prioritized needs?*

A1. The NEHI will begin work immediately to address the "next steps" identified in the "Environmental, Health, and Safety Research Needs for Engineered

nanoscale Materials" EHS report. The representatives of the sixteen U.S. Government agencies are the most experienced and scientifically qualified in the U.S. Government to consider nanotechnology issues. They all recognize the importance of completing this effort as part of the United States' commitment to realizing the benefits of nanotechnology in a manner that is responsible and that protects health and the environment.

An important next step is development of a more detailed inventory of the research currently being conducted by the NNI funded agencies. This will involve working through the OMB to get information so that we can make assessments as to the extent that current research is addressing the priority work of the five research areas identified in the research needs report.

As for a completion date, we will be in a better position to define this following our receipt and assessment of the information on the current research programs funded under the NNI. We see ourselves moving expeditiously to address the issues and produce a report that is credible and endorsed by all the U.S. Government's agencies represented in NEHI. In the meantime, research related to all five research areas is continuing to be supported in increasing amounts by NNI agencies, including EPA, NSF, NIOSH, NIH, DOD, and DOE.

We understand the importance of this issue to the Committee and to the United States maintaining its dominance in the development of nanotechnology that is safe for both the U.S. consumer and the environment. We believe that the process we are following will enable achievement of these goals.

Q2. In responses to questions at the hearing, the agency witnesses seemed to be saying the current planning/coordinating mechanism for EHS research based on the NEHI working group will be able to produce an EHS research plan or road-map, consisting of a cross-agency set of specific research priorities, timelines, and associated funding targets broken out by agency. What adjustments are needed to the way NEHI functions or to the way it is staffed to achieve this goal in a timely way?

A2. Adjustments are not needed at this time in order for the NEHI to perform a gap analysis and to address any areas that such an analysis might suggest are not being adequately investigated. NEHI members represent sixteen agencies, plus OMB and OSTP. NEHI is supported by the full-time staff of the National Nanotechnology Coordinating Office. The sixteen agencies include agencies that have nanotechnology R&D budgets, as well as those that do not, but that have a mission interest in the subject.

The NEHI process is significant in terms of the credibility of the products produced. It is not a top-down process. The NEHI process is a collaborative approach to very complex, scientific issues. The collaboration brings to bear the collective expertise of the many agencies involved and provides for their ongoing buy-in-this would not be achieved with a top-down approach. NEHI members also recognize the importance of public input in this process and will develop the means to achieve this objective. We also recognize that the process of obtaining public input adds to the time required.

NEHI does not produce funding targets for the NNI funded agencies. The NEHI report serves to inform and guide the funding agencies in their respective funding processes, which involve OMB.

All the NEHI agencies endorse the continuation of the process followed in the development of the NEHI EHS Report. This collaborative process takes time, but the process is sound and in the best interest of the United States in maintaining its dominance in the development of nano-engineered products that are safe to both the U.S. consumer and the environment.

Q3. How frequently does the NEHI working group meet (include the schedule of meetings during the past 12 months), and do most members attend meetings (provide the list of current members)?

A3. The NEHI Working Group has met on an approximately monthly schedule starting in March 2004. As requested, the meeting schedule for the past 12 months is provided in Enclosure 1. This schedule omits many meetings, both face-to-face and teleconference meetings, by several drafting groups during the six months prior to the publication of the research needs document. Over 75 percent of the NEHI Working Group members normally participate in the meetings. A roster of current members of the NEHI Working Group is provided in Enclosure 2.

Q4. Does the NEHI working group attempt to develop a funding target for the overall EHS research effort under the NNI, as well as funding requirements to achieve specific research goals? What was the role of the NEHI working group

in developing the funding estimate for EHS research shown in the FY 2007 NNI budget supplement report?

A4. The NEHI does not incorporate any funding considerations for EHS research under NNI in any of its report development. NEHI was not involved, as a body, in developing funding estimates for the fiscal year 2007 NNI budget supplement report. Individually, NEHI members, representing their respective agencies on the Nanoscale Science, Engineering and Technology (NSET) Subcommittee, were involved.

NEHI's process provides for the development of collaborative reports for which there is buy-in during the development process by all the agencies involved. This process also involves OMB, a significant collaborator in the development of the required agency budgets.

Q5. Do you believe the NEHI working group's charter prevents or impedes it from developing budget requirements for achieving EHS research objectives?

A5. According to the NEHI charter, one purpose of the working group is to "facilitate the identification, prioritization, and implementation of research and other activities required for the responsible research, development, utilization, and oversight of nanotechnology, including research on methods of life-cycle analysis." Agency budgets must be developed within the larger context of agency missions and priorities. By developing a consensus among NEHI members regarding priorities in the area of EHS research related to nanomaterials, NEHI enables the agencies that fund research related to engineered nanoscale materials to better assess and justify programs in this area within their own organization and to OMB.

Q6. By what means do industry and other interested non government entities have their views considered by the NEHI working group? Does NEHI hold any open meetings with non-government attendees?

A6. In the development of the NEHI EHS Report, other reports were used as information sources. Specifically, a report developed by the chemical and semiconductor industries was used. We also reviewed reports from the Royal Society/Royal Academy of Engineering in the United Kingdom and a report funded by the European commission.

In past meetings of NEHI, we have had presentations from non-government organizations including the Chemical Abstract Service, March 2004; Intel, Cooperative Boards for Advancing Nanotechnology-EHS, on the group's suggested research targets, October, 2005; and National Research Council's Board on Environmental Studies and Toxicology, March, 2005. We will continue to take advantage of these opportunities as we continue our work.

All members of NEHI are committed to a more formal process that involves the industry and other interested non-government experts, especially in identifying priority areas. The development of this process will be a priority for NEHI as we address the next steps identified in the first NEHI document on environment, health, and safety of engineered nanoscale materials.

Q7. Has the NEHI working group attempted to coordinate EHS research funded under the NNI with related research being carried out abroad?

A7. In furtherance of the efforts of the NSET Subcommittee and NEHI to address the significant issues of nanotechnology standards development, NSET and NEHI members are working in a collaborative manner with representatives from this industry and academia, and with our non-U.S. counterparts. This activity includes participation by NSET and NEHI members on the American National Standards Institute Technical Advisory Group to the International Organization for Standards Technical Committee on Nanotechnologies, ASTM International E56 Committee, and the Institute of Electrical and Electronics Engineers Committees on Nanotechnology. Additionally, members are collaborating with the U.S. National Committee Technical Advisory Group for the newly formed International Electrotechnical Commissions' technical committee (TC) 113, on Nanotechnology Standardization for Electrical and Electronic Products and Systems.

In addition, the nanotechnology funded agencies, through their normal activities with their foreign counterparts, will collaborate, where appropriate. This would not be an activity of the NEHI, but relevant information would be reported to NEHI.

Recently, the Global Issues in Nanotechnology Working Group (GIN) was chartered as a formal working group under the NSET. Chaired by the State Department, it has representation from the offices of the NNI participating agencies that handle international science and technology issues. The GIN provides review, input,

and feedback on documents and other materials for international activities that relate to nanotechnology.

Just getting underway is an international activity within the Organization for Economic Cooperation and Development. A new working party on manufactured nanomaterials is meeting for the first time this month in London. The main objective will be to address issues related to environmental, health, and safety implications of manufactured (or engineered) nanomaterials, including sharing information on research efforts underway and identifying opportunities for cooperation. The NNI participation in this effort will be coordinated through both the NEHI and the GIN.

Q8. In his testimony at the hearing, Dr. Maynard suggested a mechanism for government to partner with industry to fund EHS research that would support the needs of government in formulating a regulatory framework for nanomaterials and the needs of industry on how to develop nanotechnology safely. The idea is to use the Health Effects Institute model, which studies the health effects of air pollution. What are your views on this suggestion: would this be a workable approach for instituting a government/industry partnership for support of EHS research related to nanotechnology?

A8. The involvement of a third party organization such as Health Effects Institute to conduct nanotechnology health and environment research can be an effective means to address specific needs when there is a commitment by both industry and government to provide sustained funding. Without this commitment, it can become unproductive. We are not aware of a nanotechnology industry organization that can provide the sustained funding necessary to support this research.

ATTACHMENT 1

**Meeting Schedule of the
Nanoscale Science, Engineering, and Technology Subcommittee's
Nanotechnology Environmental and Health Implications Working Group
September 2005 to September 2006**

<u>Meeting Date</u>	<u>Meeting Location</u>
September 12, 2005; 1:00 -3:00 pm	NSF Room 1235, 4201 Wilson Blvd. Arlington
October 14, 2005; 8:30 – 11:00 am	White House Conference Center; Truman Room
November 7, 2005; 1:00 – 3:00 pm	NSF Room 1235, 4201 Wilson Blvd. Arlington
December 16, 2005; 1:00 – 3:00 pm	Environmental Protection Agency
January 17, 2006; 9:00 – 11:00 am	NSF Room 1235, 4201 Wilson Blvd. Arlington
February 14, 2006; 9:00 – 11:00 am	I.T.S. large conference room, Suite 800, at 4100 North Fairfax Drive, Arlington
May 4, 2006; 10:00 – Noon	NSF Rm. 110, 4201 Wilson Blvd. Arlington
May 24, 2006; 1:00 – 4:00 pm	FDA, 5600 Fishers Lane in Rockville (Drafting Team Leaders)
June 23, 2006; 9:00 – 11:00 am	NSF Rm. 1235, 4201 Wilson Blvd. Arlington
August 2, 2006; 1:00 – 4:00 pm	NSF Rm. 535, 4121 Wilson Blvd., Arlington

ATTACHMENT 2

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
 COMMITTEE ON TECHNOLOGY (CT)
 SUBCOMMITTEE ON NANOSCALE SCIENCE, ENGINEERING, AND TECHNOLOGY (NSET)
 NANOTECHNOLOGY ENVIRONMENTAL AND HEALTH IMPLICATIONS (NEHI) WORKING GROUP

NEHI Working Group Chair: Norris Alderson

NEHI Executive Secretary: Catherine Alexander

Department and Agency Representatives

Office of Science and Technology Policy (OSTP)	Department of Transportation (DOT)	National Institute for Occupational Safety and Health (NIOSH/CDC/DHHS)
Celia Merzbacher	William Chermicoff	Paul Middendorf
Kevin Geiss	Environmental Protection Agency (EPA)	Vladimir Murashov
Office of Management and Budget (OMB)	Flora Chow	National Institute of Standards and Technology (NIST/DOC)
Nancy Beck	Kevin Dreher	Dianne Poster
Keith Belton	Jeremiah Duncan	John Small
John Kraemer	Stephen Lingle	National Science Foundation (NSF)
Margaret Malanoski	Nora Savage	Enriqueta Barrera
Consumer Product Safety Commission (CPSC)	Philip Sayre	Cynthia Ekstein
Mary Ann Danello	Food and Drug Administration (FDA)	Lynn Preston
Trey Thomas	Norris Alderson	Mihail Roco
Cooperative State Research, Education and Extension Service (CSREES/USDA)	Robert Bronaugh	James Rudd
Monte Johnson	Stanley Brown	Occupational Safety and Health Administration (OSHA)
Department of Defense (DOD)	Richard Canady	William Perry
Randy Cramer	International Trade Commission (ITC)	Val Schaeffer
David Sheets	Elizabeth Nesbitt	Loretta Schuman
Department of Energy (DOE)	National Aeronautics and Space Administration (NASA)	U.S. Geological Survey (USGS)
Jay Larson	Minoo Dastoor	Sarah Gerould
John Miller	National Institutes of Health (NIH/DHHS)	Steven Goodbred
Ken Rivera	Travis Earles	
Paul Wambach	Scott McNeil	
Department of State (DOS)	Sally Tinkle	
Christopher Rothfuss	Nigel Walker	

ANSWERS TO POST-HEARING QUESTIONS

Responses by Arden L. Bement, Jr., Director, National Science Foundation

Questions submitted by Chairman Sherwood L. Boehlert

Q1. In his testimony at the hearing on September 21, Dr. Andrew Maynard from the Wilson Center recommended that the government should ask the Board on Environmental Studies and Toxicology of the National Academies of Science to help develop a long-term research agenda and conduct rolling reviews for nanotechnology environmental and safety research. Dr. Maynard also recommended that the government should contract with the Health Effects Institute to manage and/or perform some of the highest priority research. What is your view of Dr. Maynard's recommendations?

A1. The National Research Council (NRC) completed its report on the National Nanotechnology Initiative (NNI) with a special section on Environmental, Health and Safety (EHS) in October 2006. The report was requested by Congress and was sponsored by NNI participating agencies. The report evaluated the status of EHS research and provides general guidance for future work. A subsequent NRC study will begin in 2007, and EHS issues will be addressed. The NRC will conduct rolling reviews for nanotechnology, including EHS. The NRC panel may be asked to address additional issues, and include the Board on Environmental Studies and Toxicity in the evaluation. However, another parallel study would be duplicative.

Regarding the issue of management and performance of highest priority research, the mission-oriented agencies are best equipped to address various aspects of the EHS issues. The problems are too complex and diverse to be addressed by a single group in a single institute. A coordinated approach among existing federal agencies is appropriate. A single institute may not have the expertise in all areas, and may not be able to respond effectively in a fast evolving field. In addition, we believe that basic research funding should be accomplished through a competitive, merit-based process.

Q2. Does the National Science Foundation (NSF) issue targeted solicitations for research focused on specific potential environmental or safety risks associated with nanotechnology? If not, please explain how NSF addresses the highest priorities in nanotechnology environmental and safety research? Are there are additional ways to target NSF's solicitations to specific risk-based questions, while still preserving the strengths of NSF's investigator-driven model of research?

A2. The annual NSF program solicitation "Nanoscale Science and Engineering" in the interval FY 2001–2005 included one theme related to nanoscale processes in the environment and another theme on societal implications. The NSF program solicitation "Active Nanodevices and Nanosystems" in FY 2006–2007 has a major theme on societal dimensions of nanotechnology. In the last two years (FYs 2006–2007) NSF has partnered with the Environmental Protection Agency (EPA), National Institute for Occupational Safety and Health (NIOSH) and the National Institute of Environmental Health Sciences (NIEHS) for a separate program solicitation on toxicity. All themes are aligned with the NSF mission of creating fundamental knowledge, establishing the infrastructure including human resources, and supporting nanotechnology education. NSF plans to continue to emphasize the EHS and Ethical, Legal, and Societal Implications (ELSI) areas. We will include environmental aspects in program descriptions, and support workshops to stimulate proposals in the field.

NSF co-sponsored the first (2000) and second (2003) workshops on Societal Implications of Nanoscience and Nanotechnology in order to highlight the key research topics. NSF co-sponsored with EPA and the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee the grand challenge workshop on the environment; the report on those proceedings is expected to be published in November 2006. Also, NSF organized other topical workshops on the environment to identify the research trends and stimulate interest in the community.

Q3. How has NSF decided how much money to allocate to nanotechnology environmental and safety research? Why is the funding level proposed in NSF's fiscal year 2007 budget request so low compared to what is recommended by the Wilson Center and by Lux Research?

A3. NSF identifies key knowledge gaps and the level of funding needed to address the issues through the process described in the following paragraph. Because of NSF's critical impact on building a fundamental body of knowledge, specialized fa-

cilities and qualified people, NSF funds a large fraction of the overall NNI investment in Societal Dimensions: \$59 million (72 percent) of the \$82.1 million total in the FY 2007 Request, and \$51.5 million (72 percent) of \$71.7 million in the FY 2006 estimation (see The NNI—Supplement FY 2007 Budget, page 36–37). Of the total NSF contribution to NNI (\$373 million), about 16 percent is for societal dimensions of which seven percent is specifically for EHS. These percentages are in the range of those recommended on average for all of NNI by the Woodrow Wilson Center (WWC) and Lux Research (about four percent for EHS recommended by WWC and about nine percent recommended by Lux Research on average for all agencies).

The NSF funding level is established following an annual evaluation process where input is sought from the research community, industry, and other organizations. All NSF proposals under NNI are evaluated by merit review. Also, NSF has an annual process of establishing overall priorities for nanoscale science and engineering research, including:

- (a) *NSET Subcommittee*: Results from periodic workshops and meetings with the communities are synthesized by program directors and discussed in the NSET Subcommittee and its working groups;
 - (b) *National context*: NSF contributes to and coordinates its NNI research and education activities through the Nanoscale Science, Engineering and Technology Subcommittee (NSET) of the National Science and Technology Council (NSTC), as a cross-cutting priority reported to the Office of Management and Budget (OMB), and a national priority of the Administration. NSF participates in all NNI workshops, research directions and planning meetings and is coordinating its program with the work done by other agencies in the general context of R&D, infrastructure and education needs;
 - (c) *International context*: NSF organized the first “International Dialogue on Responsible Nanotechnology” conference which included 25 countries and the European Union (EU) and was held in the U.S. in June 2004, and contributed to the second in July 2006 in Japan. Other international interactions have been developed with the Organization for Economic Cooperation and Development (OECD), international standards and other international organizations. NSF organized bilateral meetings with the European Commission, Japan, Korea, Switzerland, India, China, Ireland, and others in order to identify research directions and develop collaborations. NSF has recently funded an international project on identifying EHS research needs, and has interactions with the EU and Japan on future joint research funding activities in societal dimensions;
 - (d) *Industry perspective*: A joint NNI-industry working group on EHS with the electronic and chemical industries has resulted in a report on EHS Research Needs (2005) and periodically provides input to NSF staff;
 - (e) *Public and Non-Governmental Organizations (NGOs)*: NSF receives feedback through surveys and periodical interactions. For example, NSF has supported surveys that are used as a reference in setting up the new Network for Nanotechnology in Society. All Nanoscale Science and Engineering Centers (NSEC) and nanotechnology networks supported by NSF are encouraged to have public outreach activities, and two networks have a well-defined task in this area, the Network for Nanotechnology in Society and the Network for Informal Science Education;
 - (f) *Annual Grantees Meetings and other evaluation activities*: NSF’s Committees Of Visitors (COVs), NSF’s Directorate Advisory Committees, OMB’s Program Assessment Rating Tool (PART), Presidential Council of Advisors for Science and Technology (PCAST) review);
 - (g) *Interagency Coordination via NSTC/NSET and its three working groups*: Nanomaterials Environmental and Health Issues (NEHI), Nanotechnology Innovation and Liaison to Industry (NILI), Global Issues in Nanotechnology (GNI), and Nanotechnology Public Engagement Group (NPEG).
- Q4. *In your testimony on September 21, you laid out some specific priorities for nanotechnology environmental and safety research. To what extent do these priorities overlap with the research that other federal agencies are sponsoring? To what extent do these priorities fill research gaps identified in the Wilson Center report? Of the research priorities that the Wilson Center identified, are there some priorities that NSF does not plan to investigate?*

A4. There is very little, if any, overlap. The topics covered by NSF align with the agency’s mission and cover some of the top recommendations made by both WWC and Lux Research for fundamental understanding, infrastructure, and education in

the field of nanotechnology. The mission-oriented goals for testing the toxicity of specific nanomaterials and exposure to the digestive system are best covered by the respective mission oriented agencies.

Q5. Please explain the degree to which, and how, NSF's agenda for nanotechnology environmental and safety research is shaped by interagency coordination, and how it is shaped by the need to inform potential regulation.

A5. NSF coordinates closely with other agencies in planning to eliminate duplication of effort and ensure effective knowledge transfer. NSF's agenda in this area is defined by the fundamental knowledge gaps, infrastructure and education needs.

NSF develops its strategic and annual planning, and its collaboration with other participating agencies in NSET and NSET's Nanomaterials Environmental and Health Issues (NEHI) Working Group. NSF conducts fundamental research in EHS according to its mission, which complements the more practical approach of EPA, toxicity studies by the National Institutes of Health (NIH), and regulatory activities by the Food and Drug Administration (FDA) and NIOSH. This research provides a broad-based foundation of knowledge, trained people and suitable laboratory infrastructure for the mission-specific applied R&D done by the regulatory agencies. NSF-sponsored research and education results have long-term, broad impact and may be used by multiple agencies. All NSF awards are listed on the web site and searchable by programs, authors, and keywords. In addition, NSF has communicated its results at periodic interagency meetings and workshops, including grantees workshops.

Questions submitted by Representative Bart Gordon

Q1. NSF funds well over half of all EHS research under the NNI. How specific are NSF's announcements to the research community regarding funding opportunities in this area? That is, does NSF direct the attention of potential grant awardees to research questions of high relevance to the regulatory agencies responsible for dealing with the human health and environmental risks of nanomaterials, and what percentage of the EHS funding available from NSF would fall into this category of directed basic research?

A1. NSF has allocated a high percentage of its investment in nanotechnology in the EHS area in order to define the key science and engineering issues, prepare the scientific foundation for environmental implications, develop the research infrastructure and train suitable workers in the field. NSF conducts fundamental research in EHS according to its mission, which complements the more practical approach of EPA, toxicity studies by NIH, and regulatory activities by FDA and NIOSH. NSF has encouraged research in the fundamental aspects of EHS partially by its program solicitations and several core program descriptions, as well as workshops and conferences on these topics.

Q2. In his testimony at the hearing, Dr. Maynard suggested a mechanism for government to partner with industry to fund EHS research that would support the needs of government in formulating a regulatory framework for nanomaterials and the needs of industry on how to develop nanotechnology safely. The idea is to use the Health Effects Institute model, which studies the health effects of air pollution. What are your views on this suggestion? Would this be a workable approach for instituting a government/industry partnership for support of EHS research related to nanotechnology?

A2. We believe that fundamental research on nanotechnology EHS issues will be advanced most effectively by supporting researchers at academic institutions using merit review. The role of government is in creating the knowledge foundation for industry to apply knowledge, general principles and reference data to various applications. It is not clear that placing all resources in one place for a complex problem with multiple stakeholders (government, various industries with proprietary claims, public, NGOs) would lead to superior results.

Q3. In responses to questions at the hearing, the agency witnesses seemed to be saying the current planning/coordinating mechanism for EHS research based on the NEHI working group will be able to produce an EHS research plan or road-map, consisting of a cross-agency set of specific research priorities, timelines, and associated funding targets broken out by agency. What adjustments are needed to the way NEHI functions or to the way it is staffed to achieve this goal in a timely way?

A3. NEHI is a working group that provides coordination in the field of EHS and reports to NSET. NEHI plays an advisory role to agencies. The Office of Science and Technology Policy (OSTP) and OMB coordinate the research and development plans, set priorities with input from agencies, and approve budgets for NNI each year, including for EHS efforts. Accordingly, only agencies with financial responsibility and under guidance from OMB and OSTP can set priorities and allocate funding. No changes are needed in the NEHI function and staffing.

Questions submitted by Representative Brad Sherman

This hearing focuses on the safety impacts of nanotechnology. I have concerns about the implications of nanotechnology that have not yet been adequately addressed and are often incorrectly dismissed as “science fiction.” It is said that computer engineering can be referred to as “dry nanotechnology,” that generic engineering can be referred to as “wet nanotechnology,” and that the implantation of computer chips and similar devices into a human or other biological organism is “damp nanotechnology.” Thus, the term nanotechnology encompasses the most interesting cutting-edge scientific research. It seems the science that will affect our lives in the biggest way is mighty small, in fact, nano-small. All three types of nanotechnology could well lead to what I call “engineered intelligence,” i.e., the creation of self-aware entities with intellectual capacities for exceeding the brightest human. Computer engineering (dry nanotechnology) is likely to create artificial intelligence exceeding humans within 25–30 years, according to the consensus of experts who testified before our committee on April 9, 2003. The time will come when genetic engineers will be able to create a 1,000 pound mammal with two fifty pound brains capable of a perfect score on the LSAT. And perhaps the first entities with super-human intelligence will be humans with substantial computer chip implants capable of thinking in ways no ordinary human has. In any case, I refer to all three of these nanotechnologies (dry, wet and damp) when I use the term engineered intelligence.

Dr. Bement, in your written testimony you mention the three main categories of what the National Science Foundation (NSF) characterizes as the “societal dimensions” of nanotechnology and you also go on to say that each of these categories is indispensable. My concern falls within the category of “ethical, legal and other social issues.” The ethical and societal repercussions of engineered intelligence should be studied.

Q1. Please describe in detail the projects that are funded by the National Science Foundation, which address the ethical and societal concerns accompanying the development of nanotechnology. Which of these focus on engineered intelligence in general or artificial intelligence in particular? If there are no such projects, what is the NSF's plan to promote studies addressing these concerns?

A1. The National Science Foundation is investing \$4.8 million in FY 2006 and is seeking \$5.4 million in the FY 2007 Request to Congress for ethical, legal, and social issues research and education. The NSF is funding several projects addressing ethical and social concerns of nanotechnology including: two major centers devoted to the examination of nanotechnology in society at the University of California Santa Barbara (UCSB) and Arizona State University (ASU); two nanotechnology in society research groups, one at Harvard/UCLA and the other at the University of South Carolina; two grants for Nanotechnology Interdisciplinary Research Teams (NIRTs) at the University of Minnesota, and Northeastern; several Nanotechnology Exploratory Research (NERs) grants; two Ethics Education in Science and Engineering (EESE) grants that involve ethical issues associated with nanotechnology; and several standard research grants funded through NSF programs. In addition, the National Nanotechnology Infrastructure Network (NNIN) includes activities related to societal and ethical issues, and a number of Nanoscale Science and Engineering Centers (NSECs) include research components on societal and ethical issues. Most of these projects address a range of mid- and long-range ethical and societal issues including personal privacy, security, identity, human enhancement, regulatory capacity, public perceptions and acceptance, and media coverage.

Although none of the above projects specifically addresses the ethical and societal issues of engineered intelligence or artificial intelligence, three projects directly engage ethical issues associated with nanotechnology and human enhancement. The Center for Nanotechnology in Society at ASU has a research focus on human identity, enhancement and biology. The NSEC for Molecular Function at the Nano/Bio Interface at the University of Pennsylvania has an ethics component. A recently awarded standard research grant to scholars at Dartmouth and Western Michigan University will examine ethical issues associated with human enhancement and

nanotechnology, particularly those that may be made possible with nanomaterials and nanoelectronics, e.g., nanotechnologically-augmented vision.

Q2. It is widely recognized that information about the risks of nanotechnology, to be useful, needs to be communicated to the potential users of that information in an effective way. Information that is not the product of an ongoing dialogue with various stakeholders, such as public health officials, theologians, philosophers, representatives of non-profit organizations, the private sector, and the general public, is not likely to be seen as credible by such stakeholders. Dr. Bement, please describe for me the NSF's plan for ensuring an ongoing dialogue with the public about nanotechnology issues so that the results of ethical and societal studies are valuable and usable for stakeholders. Please particularly focus on the ethical and societal research regarding the impacts of nanotechnology's potential creation of engineered intelligence in each of the three forms I have outlined above.

A2. NSF has activities in formal and informal education for nanotechnology, as well as public surveys and public participation. For nanotechnology education and outreach alone, NSF has allocated \$24.5 million in FY 2006 and \$28.0 million in the FY 2007 Request to Congress.

We have several projects that specifically address the need to ensure an ongoing dialogue with the public on nanotechnology.

- Nanotechnology: The Convergence of Science and Society (ESI-0452371, Oregon Public Broadcasting, Needham) is producing three one-hour television programs for national broadcast on the social, ethical, legal, and environmental implications of nanotechnology based on the Fred Friendly Seminar format, accompanied by community-based outreach efforts and a web site.
- The Nanoscale Informal Science Education Network (ESI-0532537, Museum of Science, Bell), which is creating exhibits and media to educate the public about nanoscience and technology, includes development and implementation of public forums in science museums designed to engage adults in discussing potential societal impact.
- Other projects, such as Earth & Sky Nanoscale Science and Engineering Radio Shows (ESI-0426417, EarthTalk Inc., Britton) that will increase general public awareness of nanotechnology and its role in our lives.

There are numerous other activities associated with the projects outlined in the answer above that are designed to foster an ongoing and informed dialogue with various stakeholders including the public. For example, Science Cafes, at which nano-scientists talk about their research and afford members of the public an opportunity to raise questions and concerns, are being held on a regular basis at the University of Wisconsin and ASU. The University of South Carolina has organized several Citizens' Schools of Nanotechnology where members of the public read and discuss nanotechnology and related societal issues over a several-week period. The Harvard/UCLA research project is developing a pilot NanoEthicsBank providing an online database of articles, journals, reports, and meeting minutes related to nanotechnology and ethics; the NanoEthicsBank is accessible to the public and other stakeholders. Several projects, including those at ASU, UCSB, and North Carolina State, have public deliberation activities related to nanotechnology and society. Finally public opinion surveys, as well as scientist surveys, associated with various aspects of nanotechnology and society are being conducted as part of a number of these projects. In all these instances, the local media are utilized to inform the public about the activities.

In addition to the activities focusing on public knowledge, understanding and concerns, several workshops on nanotechnology and society issues have been held in conjunction with NSF funded projects. At these, representatives from academia, non-profits, government and industry have participated. For example, Michigan State held a workshop on what nanotechnology can learn from the experiences of biotechnology. A workshop on ethical issues and nanotechnology is being planned and will be held at ASU.

Q3. Roughly two percent of the National Science Foundation's FY 2007 request for the National Nanotechnology Initiative goes to "ethical, legal, and social issues," while about eight percent is directed toward environmental, health and safety research. Dr. Bement, you state in your submitted testimony that "ethical, legal, and social issues" are an important dimension of the study of nanotechnology's societal issues. Then, why is so little of the funding for the National Nanotechnology Initiative (NNI) directed towards the "ethical, legal, and social issues" category?

A3. The support for “ethical, legal, and social issues” was determined by the need for funding the relevant and meritorious social sciences projects, the level of current developments in the field and formation of a multi-disciplinary community, and the funding needs of competing areas such as Environmental, Health and Safety (EHS). The current investment is beginning to create a community with critical mass for advancing research and understanding of the ethical, legal and social issues associated with nanotechnology.

Now, leaving the issue of engineered intelligence, I have some general questions about the NNI which are frankly less important to me than the previous questions, but I hope you will answer them at your convenience.

Q4. Is your agency involved in a systematic assessment of emerging products of nanoscale science and engineering so that you can identify possible new sources of risk at the earliest possible stage?

A4. NSF co-organized a grand challenge workshop on the environment, supports four centers for partial support of this topic, and initiated the industry-government working groups on EHS in 2003. NSF does not directly evaluate products, as that is a role that is more pertinent to other agencies and industry.

Q5. Is your agency involving researchers in the process of identifying and prioritizing research problems, to ensure that research agendas are responsive to stakeholder concerns? What societal research are you supporting to help identify the various ways that nanotechnology risk is being framed by researchers? If you are not engaged in such work, why are you confident that the research you are funding will be valuable for stakeholders?

A5. NSF provides opportunities for stakeholder input through its process of establishing priorities, including workshops with various communities, joint working groups, direct interactions, grantees meetings, and interagency exchanges. For example, NSF supports projects on safety in manufacturing, occupational health issues, implications for food and agriculture, as well as for long-term societal implications.

NSF is supporting research on different approaches to risk assessment and risk perception for nanotechnology. For example, the University of Wisconsin is studying the effect of nanotechnology on food production and risk perception. NSF is funding research and education activities to assess risk for the current and future generations of nanoproducts. All projects are subject to peer review where stakeholders are invited to participate.

Q6. According to a Congressional Research Services document, the Administration's FY 2007 request for the National Nanotechnology Initiative is a four percent decline in real dollars than what was enacted in FY 2006. Why would we decrease the funding, given the importance of the research?

A6. The Request for NNI investment has increased each year including in FY 2007 (\$1,278 million) as compared to the FY 2006 Request (\$1,054 million).

ANSWERS TO POST-HEARING QUESTIONS

Responses by William H. Farland, Deputy Assistant Administrator for Science, Office of Research and Development, U.S. Environmental Protection Agency

Questions submitted by Chairman Sherwood L. Boehlert

Q1. In his testimony at the hearing on September 21, Dr. Andrew Maynard from the Wilson Center recommended that the government should ask the Board on Environmental Studies and Toxicology of the National Academies of Science to help develop a long-term research agenda and conduct rolling reviews for nanotechnology environmental and safety research. Dr. Maynard also recommended that the government should contract with the Health Effects Institute to manage and/or perform some of the highest priority research. What is your view of Dr. Maynard's recommendations?

A1. The National Academies of Science (NAS) provides periodic reviews of the government activities under the National Nanotechnology Initiative (NNI) as required by the *21st Century Nanotechnology Research and Development Act of 2003*. The NNI is managed within the framework of the National Science and Technology Council (NSTC), the Cabinet-level council by which the President coordinates science, space, and technology policies across the Federal Government. The Nanoscale Science Engineering and Technology (NSET) Subcommittee of the NSTC coordinates planning, budgeting, program implementation and review to ensure a balanced and comprehensive initiative. The NSET Subcommittee is composed of representatives from agencies participating in the NNI.

The NSET Subcommittee members value its relationship with NAS and hope to use it in the future to receive input and feedback from the Board on Environmental Studies and Toxicology (BEST) and other NAS Boards on research directions and priorities related to environmental, health and safety. However, the agencies that participate in NSET and its Nanotechnology Environmental and Health Implications Working Group (NEHI) have already made significant progress toward a long-term research agenda with the publication in September of the report "Environmental, Health and Safety Research Needs for Engineered Nanoscale Materials," and are committed to taking steps immediately to establish priorities for their research needs. Given this progress, it seems most effective to utilize BEST and other NAS bodies to review, rather than to establish, an additional long-term research agenda. EPA believes that the current NAS role provides timely and appropriate input to the government's research agenda.

EPA supports collaboration with the private sector and other stakeholders. While EPA has a positive relationship with the Health Effects Institute on air pollution research, we believe it is too early to conclude that the same model is appropriate for nanotechnology environmental and safety research. On October 18, EPA announced its intent to develop a stewardship program that would provide a valuable collaboration with industry and other stakeholders, and which we expect to result in significant new information being made available on nanomaterials. EPA is inviting the public, industry, environmental groups, other federal agencies and other stakeholders to participate in the design, development and implementation of this program. A successful stewardship program will complement the Agency's new and existing chemical programs under the *Toxic Substances Control Act* and can help provide a scientific foundation for regulatory decisions by encouraging the development of key scientific information and appropriate risk management practices.

Q2. How has the Environmental Protection Agency (EPA) decided how much money to allocate to nanotechnology environmental and safety research? What impact will the report from the Nanotechnology Environmental and Health Implications Working Group have on EPA's nanotechnology research programs? What impact will it have on EPA's fiscal year 2008 budget request?

A2. Determinations of research budget priorities are made in the context of the Agency's overall priorities and budget needs in concert with the Agency program offices. EPA also has allocated resources to new, emerging issues, such as nanotechnology, through its Science to Achieve Results (STAR) exploratory grants. Initial results from this STAR nanotechnology research and research by others helped clarify research gaps and opportunities that were considered as EPA increased its nanotechnology budget request from FY06 to FY07. The EPA's FY08 budget process has been guided in part by the development of the Nanotechnology White Paper, which was released as a draft report in December 2005 for public comment. Over the past year, the process of developing the NEHI research needs docu-

ment has provided additional insight into EPA's research needs. EPA has developed a nanotechnology research strategy framework which, along with the White paper should advance the NEHI efforts to develop an overall federal prioritized research strategy in this area.

Q3. In your testimony on September 21, you laid out some specific priorities for nanotechnology environmental and safety research. To what extent do these priorities overlap with the research that other federal agencies are sponsoring? To what extent do these priorities fill research gaps identified in the Wilson Center report? Of the research priorities that the Wilson Center identified, are there some priorities that EPA does not plan to investigate?

A3. Our testimony on September 21 stated that EPA will conduct research to understand whether nanoparticles, in particular those with the greatest potential to be released into the environment and/or trigger a hazard concern, pose significant risks to human health or ecosystems. We stated that we are uniquely positioned to lead in the ecosystem and exposure areas. A research framework included in the White Paper identifies specific near-term priority research areas as fate, transport, transformation, exposure and monitoring, and detection technologies. The Agency has taken steps to ensure that the priority research areas will not overlap either with current research sponsored by other agencies or with their research priorities. EPA communicates regularly with other federal agencies concerning priorities through the NEHI and NSET and collaborates with other agencies on research solicitations to ensure that environmental and health issues are undertaken in a coordinated manner. For example, EPA has issued joint solicitations over the past two years with National Science Foundation, National Institute of Occupational Safety and Health and the National Institute of Environmental Health Sciences.

EPA's priorities are also consistent with those suggested in the Woodrow Wilson Center research document, which suggests the Agency give priority to the areas of exposure and monitoring/detection technologies with subsequent focus on ecotoxicity and life cycle approaches (found on pp. 34-36 of the report, <http://www.nanotechproject.org/67/7-19-06-nanotechnology-a-research-strategy-for-addressing-risk>). All of these areas are contained within the priorities identified in the recent testimony and the draft White Paper. While the Wilson Center report does not mention fate, transport and transformation explicitly, these areas are critical to understanding both exposure and toxicity—whether ecological or human—as well as life cycle considerations.

Q4. EPA released a draft white paper on its research needs for the environmental and safety impacts of nanotechnology for public comment last year. Your written testimony said that it complements the report released today. In what way are they complementary? When will the white paper be finalized? Will you be revising it based on today's report? Will the final version identify short-, medium- and long-term priorities?

A4. The Nanotechnology White Paper was recently approved by the Agency's Science Policy Council, so EPA anticipates that the final version will be released to the public soon.

The draft White Paper provides an extensive review of research needs for both environmental applications and implications of nanotechnology. To help EPA focus on priorities for the near-term, the draft concludes with recommendations on the next steps for addressing science policy issues and research needs. In addition, it includes in Appendix C, a description of EPA's framework for nanotechnology research, which outlines how EPA will strategically focus its own research program (as outlined in the September testimony) to provide key information on potential environmental impacts from human or ecological exposure to nanomaterials in a manner that complements federal, academic, and private-sector research activities. Collaboration with other researchers is a major focus of the draft paper.

EPA was represented on the committee that developed the NEHI report, and played a key role in identifying research needs. As such, there is no need to modify the white paper since the two reports complement one other. The NEHI report was designed to give an overview of environmental, health and safety research needs for all federal agencies. The research needs identified in EPA's draft White Paper were included in the NEHI report. As the NEHI prioritizes needs, those areas that fall within the mission and expertise of the EPA will be addressed in the context of the Agency's overall research priorities and budget.

Questions submitted by Representative Bart Gordon

Q1. In his testimony at the hearing, Dr. Maynard suggested a mechanism for government to partner with industry to fund EHS research that would support the needs of government in formulating a regulatory framework for nanomaterials and the needs of industry on how to develop nanotechnology safely. The idea is to use the Health Effects Institute model, which studies the health effects of air pollution. What are your views on this suggestion: would this be a workable approach for instituting a government/industry partnership for support of EHS research related to nanotechnology?

A1. EPA supports collaboration with the private sector and other stakeholders, and EPA has a positive relationship with the Health Effects Institute on air pollution research. However, we believe it is too early to conclude that the same model is appropriate for nanotechnology environmental and safety research. On October 18, EPA announced its intent to develop a stewardship program that would provide a valuable collaboration that could result in significant new information that will help the Agency better understand the potential risks and benefits of nanotechnology. EPA is inviting the public, industry, environmental groups, other federal agencies and other stakeholders to participate in the design, development and implementation of this program. A successful stewardship program will complement the Agency's new and existing chemical programs under the *Toxic Substances Control Act* and can help provide a scientific foundation for regulatory decisions by encouraging the development of key scientific information and appropriate risk management practices.

Q2. In responses to questions at the hearing, the agency witnesses seemed to be saying the current planning/coordinating mechanism for EHS research based on the NEHI working group will be able to produce an EHS research plan or roadmap, consisting of a cross-agency set of specific research priorities, timelines, and associated funding targets broken out by agency. What adjustments are needed to the way NEHI functions or to the way it is staffed to achieve this goal in a timely way?

A2. The Agency does not believe any alterations nor changes in the NEHI staffing or functionality are required to prioritize the research needs that are identified in the NEHI report. As indicated above, EPA has already developed its own prioritized research strategy, and will work with other agencies through the NEHI to develop a coordinated cross-agency set of research priorities in a timely manner.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Altaf H. (Tof) Carim, Program Manager, Nanoscale Science and Electron Scattering Center, U.S. Department of Energy

Questions submitted by Chairman Sherwood L. Boehlert

Q1. In his testimony at the hearing on September 21, Dr. Andrew Maynard from the Wilson Center recommended that the government should ask the Board on Environmental Studies and Toxicology of the National Academies of Science to help develop a long-term research agenda and conduct rolling reviews for nanotechnology environmental and safety research. Dr. Maynard also recommended that the government should contract with the Health Effects Institute to manage and/or perform some of the highest priority research. What is your view of Dr. Maynard's recommendations?

A1. Periodic reviews of the National Nanotechnology Initiative, specifically including environmental and safety aspects, are already required from both the National Academies and the President's Council of Advisors on Science and Technology (serving as the National Nanotechnology Advisory Panel) under P.L. 108–153. Initial reports from both groups have been issued (the Academies' review report, *A Matter of Size: Triennial Review of the National Nanotechnology Initiative*, was released in pre-publication form shortly after the hearing, on September 25th, 2006, and the PCAST report, *The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel*, was issued in May 2006). Both reports discussed environmental, health, and safety aspects of the initiative and it is anticipated that this topic area will appropriately receive attention in subsequent reviews by these groups.

Development of a long-term agenda for environmental and safety research is already underway via the interagency Nanoscale Science, Engineering, and Technology (NSET) subcommittee of the National Science and Technology Council and its subsidiary Nanotechnology Environmental and Health Implications (NEHI) working group. These activities are in the context of the missions, resources, and expertise of the participating agencies, and represent comprehensive coordination of federal efforts. The document prepared by NEHI and released on the date of the hearing, *Environmental, Health, and Safety Research Needs for Engineered Nanoscale Materials*, represents an initial step in the ongoing process of defining and evaluating these activities. Given the existing mandate for the National Academies to review these aspects of the National Nanotechnology Initiative and the time required from commissioning to final publication of a National Academies report, an additional review requirement by the National Academies in this area would not appear to be warranted or fruitful.

The Department of Energy is not involved with the existing work of the Health Effects Institute (HEI) and defers to other agencies with more expertise in this subject area. HEI appears to be focused on particular classes of problems, with roughly half of its core funding coming from "the worldwide motor vehicle industry" (as per its homepage, at <http://www.healtheffects.org/about.htm>). Government partnerships with, or support of, private parties can be appropriate and effective, though a preferable approach might be to define the needs and then consider competitive proposals to achieve the desired ends, rather than pre-selecting a specific party to manage and/or perform such work. This is best pursued in the context of agency missions, resources, expertise, and past experience.

Q2. In your testimony on September 21, you stated that the Department of Energy (DOE) supports research on potential environmental and safety risks associated with nanotechnology by providing uniquely capable synthesis and characterization tools, but you suggested that DOE does not sponsor or conduct targeted nanotechnology environmental and safety research. Given DOE's significant contribution to the National Nanotechnology Initiative (NNI), shouldn't DOE's contribute more directly to NNI's targeted environmental and safety research priorities?

A2. As is the case for all the agencies involved in the NNI, DOE contributes to NNI goals and priorities in the ways which align most closely with the Department's mission, resources, and expertise. The distinct nature of each agency's nanotechnology programs reflects the ongoing interagency coordination and the corresponding efforts to avoid duplication and most effectively pursue such work. DOE solicitations have not focused specifically on nanomaterials environmental and safety research, though a limited amount of work with the primary purpose of understanding trans-

port and ultimate disposition of nanoscale particles in the environment has been supported via competitive merit review as part of our geosciences research program. Other activities with important relevance to environmental and safety concerns include the operation of user facilities that provide capabilities for obtaining comparable, reproducible data; work on measurement and characterization techniques, including novel instrumentation; and development of standards and nomenclature. These activities include some which are critical and involve DOE and/or contractor staff but little or no direct funding, such as internal working group discussions of best practices among DOE-supported laboratories and participation in groups such as the American National Standards Institute and the International Organization for Standardization. Nevertheless, the Department intends to reassess its direct support of environmental and safety research as it relates to nanotechnology applications in DOE mission areas.

Q3. Please explain the degree to which, and how, DOE's investments in advanced nanotechnology facilities are shaped by nanotechnology environmental and safety research priorities, and how those investments are shaped by the need to inform potential regulation related to possible environmental and safety risks.

A3. The DOE Nanoscale Science Research Center user facilities investments have been shaped by a variety of factors including initial interagency discussions at the start of the National Nanotechnology Initiative, a series of planning workshops that attracted nearly 2,000 participants, definition of nanoscience research needs to address energy issues, and efforts to optimize the utility and accessibility of other major BES facilities for nanoscience. While the instrument suites and infrastructure investments over the past five years have not directly reflected recently-developed environmental and safety research priorities or regulatory needs, DOE representatives have made members of those communities aware of the resources that will be made available to them through the NSRCs via presentations to and meetings with program managers and grantees from EPA, USDA, NIH, NSF, and the NSET inter-agency group as a whole.

The NSRCs are part of the scientific infrastructure of the Nation. They support the specific research missions of other agencies by providing access to unique capabilities and collections of instruments and expertise that are unavailable elsewhere or impractical for many individual organizations to obtain and support. The NSRCs also provide opportunities for collaboration. The methods and practices developed and used at the NSRCs allow the collection of comparable, I reproducible data across material types and across multiple research groups through the use of standardized platforms and procedures; such consistency in measurement and characterization is critical to understanding research issues.

Q4. How are priorities for nanotechnology environmental and safety research considered in DOE's budget and planning processes for nanotechnology research and development?

A4. The NSET-NEHI report and other external documents on nanotechnology environmental and safety research needs provide guidance; agencies then make their plans for activities in this area within the framework of the NSET report(s) and based on the input and directions identified by the interagency process, third parties, the community through workshops and discussions, and a variety of other means. In the case of DOE, the budget and planning processes for nanoscience and related activities center on the mission of the Office of Science, involving fundamental research in support of long-term energy security and discovery science, and forefront scientific user facilities for the Nation. The planning for nanoscience centers rests on the principles of broad access and of facilitating leading-edge research in all areas by providing a comprehensive suite of tools and expertise.

Questions submitted by Representative Bart Gordon

Q1. In his testimony at the hearing, Dr. Maynard suggested a mechanism for government to partner with industry to fund EHS research that would support the needs of government in formulating a regulatory framework for nanomaterials and the needs of industry on how to develop nanotechnology safely. The idea is to use the Health Effects Institute model, which studies the health effects of air pollution. What are your views on this suggestion: would this be a workable approach for instituting a government/industry partnership for support of EHS research related to nanotechnology?

A1. (As answered as part of the response to Question #1 from Chairman Boehlert and repeated here.) The Department of Energy is not involved with the existing

work of the Health Effects Institute (HEI) and defers to other agencies with more expertise in this subject area. HEI appears to be focused on particular classes of problems, with roughly half of its core funding coming from “the worldwide motor vehicle industry” (as per its homepage, at <http://www.healtheffects.org/about.htm>). Government partnerships with, or support of, private parties can be appropriate and effective, though a preferable approach might be to define the needs and then consider competitive proposals to achieve the desired ends, rather than pre-selecting a specific party to manage and/or perform such work. This is best pursued in the context of agency missions, resources, expertise, and past experience.

Q2. In responses to questions at the hearing, the agency witnesses seemed to be saying the current planning/coordinating mechanism for EHS research based on the NEHI working group will be able to produce an EHS research plan or roadmap, consisting of a cross-agency set of specific research priorities, timelines, and associated funding targets broken out by agency. What adjustments are needed to the way NEHI functions or to the way it is staffed to achieve this goal in a timely way?

A2. The very aspect of the NEHI working group that causes the process to be at times lengthy is also its strength: it synthesizes and reconciles input from the many agencies involved, and thus provides a coordinated and consensus output that is reflective of the overall U.S. federal position. We believe that the current NSET and NEHI structure is the best approach to engaging the needed expertise from the member agencies to do credible, effective, and implementable planning.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Andrew D. Maynard, Chief Science Advisor, Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars

Questions submitted by Chairman Sherwood L. Boehlert

Q1. In your testimony you indicated that the interagency working group is not able to carry out the important tasks identified in the Nanotechnology R&D Act, including assessing research gaps, setting priorities, and reviewing and directing agency budgets? How would you make NEHI more effective?

A1. First, I would suggest that the NEHI working group's position under the National Science and Technology Council Committee on Technology places it at an immediate disadvantage in ensuring that targeted research informs regulation and other forms of oversight. I will expand on my reasoning behind this statement below. If NEHI does continue to be the interagency group primarily responsible for ensuring effective nanotechnology risk-research across the Federal Government, then I would propose that three changes are essential if the group is to be effective in implementing relevant parts of the *21st Century Nanotechnology Research and Development Act*:

1. The charter of the NEHI working group must be modified to increase the group's charge and authority to establish and implement a strategic nanotechnology risk research framework, which underpins nanotechnology oversight.
2. The NEHI working group must have the authority to ensure that appropriate agencies have the resources they need to conduct relevant, effective and coordinated risk research.
3. A full-time director, with appropriate staffing, must oversee the activities of the NEHI working group, with responsibility for developing and implementing a cross-agency strategic risk-research plan. The Director must be seen as an "honest broker" with no immediate ties to any government agency. The Director must also have direct access to key decision makers in both the White House and the Office of Management and Budget (OMB).

These changes will provide the tools NEHI needs to develop and implement an effective top-down strategic research framework across federal agencies, a framework that enables each agency to operate to maximum effect within its mission and competencies. However, by themselves, these changes will not guarantee success. Implementation of the recommended changes will require the support and commitment of all participating agencies, the Office of Science and Technology Policy (OSTP) and OMB. NEHI will also need new funding to cover critical research and support a full-time director. I have previously estimated that a minimum of \$100 million over the next two years needs to be spent on targeted risk-related research, with additional funding for basic and applications-focused research with some relevance to understanding risk. I would suggest that mechanisms are needed whereby additional research funds can be allocated to agencies via the NEHI group to supplement current resource-starved programs—possibly through new funds being appropriated by a relatively neutral agency, and allocated out through interagency agreements. Effective resource allocation will depend on developing a strategic research agenda within NEHI, identifying the roles of research agencies within this agenda, and enabling cross-agency collaborations.

I also recommended in my testimony to the House Committee on Science that an external organization be used to allow public and private sector co-funding of strategic environmental, health and safety research. One model explored was the Health Effects Institute, which receives funding from the Environmental Protection Agency (EPA) (both the Office of Research and Development and the Air Office) along with industry to conduct targeted research on the health effects of air pollution.

Is NEHI the most appropriate cross-agency group to assess research gaps, set priorities, and review and direct agency budgets?

I would suggest that the NEHI working group's position under the National Science and Technology Council Committee on Technology places it at an immediate disadvantage in implementing risk-related aspects of the *21st Century Nanotechnology R&D Act*, and in particular in ensuring that targeted research informs regulation and other forms of oversight. The paradigms and mechanisms that drive research for effective risk assessment and management differ significantly from those that drive basic science. There is a significant overlap between these two areas—applied risk-research will always build on basic science. But if applied re-

search aimed at assessing and managing risk is approached in the same way as exploratory research, there is a danger that resulting research programs will not be responsive to the needs of regulators, industry and the public. The National Nanotechnology Initiative (NNI) has been extremely successful in stimulating exploratory research across many areas of science, which will underpin new applications and new ways of managing risk. Yet, there are indications that approaches to *applied* risk-research within the NNI are clouded by following an exploratory research-paradigm. I would highlight just three examples that support this observation:

- The current NEHI Terms of Reference focus on facilitating and supporting bottom-up research programs and strategies—an approach that is ideal for fostering collaborative investigator-driven exploratory research, but is not responsive to assessing research gaps, setting priorities, and reviewing and directing agency budgets.
- Current investment in risk-based research is purportedly dominated by the National Science Foundation (NSF)—despite a widely recognized need for targeted risk research beyond the directive of this agency. As nanotechnology moves off the lab bench and into the marketplace, one would expect to see a significant shift in risk-related research funding to mission-driven agencies such as the EPA, the U.S. Department of Agriculture (USDA), and the Food and Drug Administration (FDA), which have direct oversight responsibilities. This is not happening.
- The recent NSET research needs document¹ refers to current research, which, while conceivably enhancing our understanding of risk in the distant future, has little practical relevance at present. Take, for instance, the cited development of Transmission Electron Aberration-corrected Microscope (TEAM) project within the Department of Energy (DOE).² From my own research, I can confidently state that, while this is a vital area of research for nano-applications, it is of only secondary importance to increasing our understanding of nano-implications.³

With the best will in the world, an effective strategic risk-research framework is unlikely to be developed and implemented if those responsible are working within the wrong paradigm, in an inappropriate framework. This is why, in my report on strategic risk research published earlier this year,⁴ I recommend that a separate interagency group be established that can address these issues within an appropriate framework.

Q2. *In your testimony you reported that the Federal Government is spending less on research on environmental and safety issues than the Federal Government claims it is spending. Why do your estimates differ so greatly with the figures reported by the Administration? What do you need to reconcile your figures with the government's accounting?*

A2. Based on the considerations outlined below, it is my opinion that the discrepancy between the NSET and the Project on Emerging Nanotechnologies (PEN) figures reflects a rather broad interpretation within NSET of research that is highly relevant to understanding the potential risks of engineered nanomaterials. Because federal agencies within the NNI remain unable to provide information on risk research at the project level, it is not possible to identify the sources of the discrepancy with any certainty.

Funding figures without access to the underlying data are largely meaningless. Understanding the potential risks of nanotechnology is complex, and identifying research that might provide insight is more than an accounting exercise. Because of

¹NSET. 2006. *Environmental, Health, and Safety Research Needs for Engineered Nanoscale Materials*. Nanoscale Science, Engineering, and Technology Subcommittee, Committee on Technology, National Science and Technology Council. September.

²Ibid, p. 15.

³Maynard, A.D. 1995. "The application of electron energy-loss spectroscopy to the analysis of ultra-fine aerosol particles." *J. Aerosol Sci.* 26(5): 757–777; Maynard, A.D. and L.M. Brown. 2000. "Overview of methods for analysing single ultra-fine particles." 358(1775): *Philosophical Transactions of the Royal Society of London Series a-Mathematical Physical and Engineering Sciences*. 2593–2609; Maynard, A.D., Y. Ito, et al. 2004. "Examining elemental surface enrichment in ultra-fine aerosol particles using analytical Scanning Transmission Electron Microscopy." *Aerosol Sci. Tech.* 38: 365–381.

⁴Maynard, A.D. 2006. *Nanotechnology: A Research Strategy for Addressing Risk*. Washington, DC: Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars, July. Available at: <http://www.nanotechproject.org/reports>.

this, the PEN inventory of health and environmental implications research⁵ categorizes information in a way that captures the complexity of current research, and provides a resource for anyone interested in planning relevant, coordinated and strategic research. Open-access to the inventory also allows anyone to challenge or validate conclusions drawn from the information it contains. I would encourage the Federal Government to take a similar approach, and indeed would consider this essential for developing strategic research plans that identify and address critical research needs. To achieve this, information must be collated, categorized and made available at the project level. An open accounting of the federal research portfolio would also make it easier for industry to determine where and how it could partner with government to fund risk research, as well as supporting effective international cooperation on strategic research.

Examining the differences between PEN and NSET risk research estimates

The NSET annual spending figure purportedly reflects research investment where the primary purpose is to understand and address potential risks to health and the environment. Research is either included in or excluded from the reported figures—there is no gray area of research that might have some relevance, but does not have a primary purpose of understanding risk. It must be assumed that interpretation of what constitutes relevant research is undertaken at the agency level and may be based on subjective judgments. Unfortunately, without information on which projects NSET does and does not account for, it is not possible to comment in depth on how this definition has been applied.

In contrast, the PEN inventory categorizes research according to its relevance to understanding risk (high, substantial, some or marginal), allowing an inherently more sophisticated assessment of current activity. In this scheme, *highly relevant research* is directly focused on addressing risk, while research having lesser relevance might be focused on applications of nanotechnology, general characterization methods or non-engineered nanomaterials. In addition, research into incidental nanomaterials (such as vehicle emissions and naturally occurring nanoparticles) is classified separately from research specifically focused on engineered nanomaterials. This distinction is important—research into the impact of incidental nanomaterials can help inform our understanding of nanotechnology risks, but it is misleading to account for it as being directly relevant to nanotechnology.

From the PEN inventory, it is estimated that the Federal Government invested \$11 million on research, which is *highly relevant to engineered nanomaterials* in 2005 (Table 1). This added sophistication in accounting *might* explain some of the \$28.7 million difference between PEN and NSET estimates. For instance, research on welding fume in the workplace—an incidental nanomaterial—has been included in the PEN inventory as it is useful for understanding purposely made nanomaterials. Yet this research has *not* been included in the estimated \$11 million—precisely because it is *not* specifically focused on engineered nanomaterials. There is no way of telling at present whether the NSET has included this, and similar research projects, in spending estimates.

Table 1. Comparison of NNI-estimated annual nanotechnology risk-related research funding to estimates from the Project on Emerging Nanotechnologies. All figures are in \$millions

Agency	NNI-estimated risk-related annual R&D	PEN-estimated risk-related annual R&D (highly relevant research)	Difference
NSF	24.0	2.5	21.5
DOD	1.0	1.1	- 0.1
DOE	0.5	0	0.5
HHS (NIH)	3.0	3.0	0
DOC (NIST)	0.9	0	0.9
USDA	0.5	0	0.5
EPA	4.0	2.3	1.7
HHS (NIOSH)	3.1	1.9	1.2
DOJ	1.5	0	1.5
Totals	38.5	10.8	28.7

⁵ PEN. 2005. *Nanotechnology Health and Environmental Implications: An Inventory of Current Research*. Washington, DC: Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars. Available at: <http://www.nanotechproject.org/18/esh-inventory>.

The DOE, Department of Commerce (DOC), USDA and Department of Justice (DOJ) together account for a \$3.4 million difference between the PEN and NSET figures. Information on what research DOJ is funding on nanotechnology risk research is not directly available, and is thus not included in the PEN inventory. For the other three agencies, it is likely that research accounted for by NSET as primarily addressing nano-risk was not considered *highly relevant* in the PEN inventory. For instance, a DOE project led by Dr. Kaufmann on controlling the shape, size and reactivity of metal oxide nanoparticles is categorized as having *substantial*, but not *high relevance* to risk in the PEN inventory. Likewise, a NIST project on developing microsphere-based spectroscopic instruments is categorized as having *marginal relevance* to risk in the PEN inventory. It is unclear whether NSET included these projects in its accounting.

The EPA and the National Institute for Occupational Safety and Health (NIOSH)—two federal agencies charged with supporting research to understand and reduce adverse health and environmental impacts—account for a \$2.9 million difference between PEN and NSET figures. Discrepancies associated with EPA may well be due to differences in accounting—the NSET—reported figure for EPA includes a research investment in nanotoxicology grants for the period of fiscal year 2006–fiscal year 2009, while the PEN figure reports mean annual EPA spending on risk-relevant research. Differences in the NIOSH estimates result from the lack of project-specific information being directly available from the agency. In the absence of further information, the reported \$3 million per year investment was factored by the number of NIOSH projects in the PEN inventory that are *highly relevant* to understanding the potential risks of engineered nanomaterials.

By far the largest discrepancy is with estimated NSF funding—with a difference of \$21.5 million per year between NSET and PEN. This is likely due to different interpretations of relevant research. Once again, I can only speculate on why the figures are so different, without NSET providing information at the project level. However, as an agency charged with funding basic research, it is surprising to see NSF purportedly accounting for over 60 percent of research where the primary purpose is to understand and address potential risks to health and the environment—over three times the NSET-reported investment within NIOSH and EPA. This in itself is cause to question the figures.

The PEN inventory classifies many of the NSF projects as relevant to understanding risk, but not *highly relevant*. For instance, the NSF-funded Center for Biological and Environmental Nanotechnology (CBEN) at Rice University was considered *substantially relevant* to understanding risk, but the center's focus on applications as well as implications of nanotechnology precluded the research being categorized as *highly relevant*. Similarly, research into biologically compatible engineered nanoparticles to prevent UV-radiation induced damage was considered to have *some relevance* to risk, but not to be *highly relevant*.

Questions submitted by Representative Bart Gordon

Q1. In responses to questions at the hearing, the agency witnesses seemed to be saying the current planning/coordinating mechanism for EHS research based on the NEHI working group will be able to produce an EHS research plan or road-map, consisting of a cross-agency set of specific research priorities, timelines, and associated funding targets broken out by agency. Do you believe that there are adjustments that could be made to the way NEHI functions or to the way it is staffed that would allow it to achieve this goal in a timely way?

A1. From my experience as co-chair of NEHI, my knowledge of the terms of reference of the working group and my observations of the group's activity over the past year, I can only conclude that NEHI will not be able to produce an EHS research plan consisting of a cross-agency set of specific research priorities, timelines, and associated funding targets broken out by agency, within an acceptable time frame. Let me qualify this by stating that the current members of NEHI are extremely well qualified to identify and assess what research needs to be done and by whom if the Federal Government's investment in nanotechnology research is to translate into responsible industries and products. The recent NSET report on research needs attests to this. Yet, NEHI lacks the terms of reference, authority and resources to achieve what is necessary, and members of the group are often juggling many other conflicting commitments to spend the necessary time on ensuring the group functions effectively. There is, as Chairman Boehlert observed during the hearing, a sense of *urgency* in this task as more nano-based products pour into the marketplace. It is not enough to ask the right questions, they must be asked early enough so that we have time to generate practical answers. Our ability to reap the

long-term benefits of our investments in nanotechnology will depend heavily on how we address any emerging risks.

In my response to the first question from Chairman Boehlert (above), I consider three changes that I consider essential, if NEHI is to be effective in ensuring assessing research gaps are assessed, priorities are set, and agency budgets are reviewed and directed. Let me reiterate these changes here:

1. The charter of the NEHI working group must be modified to increase the group's charge and authority to establish and implement a strategic nano-risk research framework, which underpins nanotechnology oversight.
2. The NEHI working group must have the authority to ensure that appropriate agencies have the resources they need to conduct relevant, effective and coordinated risk research.
3. A full-time director, with appropriate staffing, must oversee the activities of the NEHI working group, with responsibility for developing and implementing a cross-agency strategic risk-research plan. The Director must be seen as an "honest broker" with no immediate ties to any government agency. The Director must also have direct access to key decision makers in both the White House and the Office of Management and Budget.

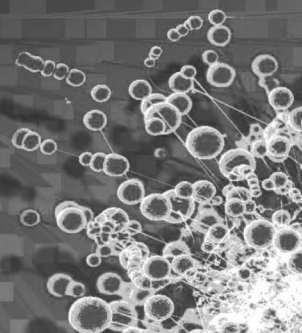
In my opinion, these changes will also enable NEHI to develop a strategic risk research framework, consisting of a cross-agency set of specific research priorities, timelines, and associated funding targets broken out by agency. Without significant changes to the way the group operates, I am extremely pessimistic that we will see an effective strategic research framework emerge that enables federal agencies to operate to the best of their ability when addressing the complex challenges that nanotechnology is raising.

Appendix 2:

ADDITIONAL MATERIAL FOR THE RECORD

**The National
Nanotechnology
Initiative**

**Environmental, Health,
and Safety Research Needs
for Engineered
Nanoscale Materials**



About the National Science and Technology Council

The National Science and Technology Council (NSTC) was established by Executive Order on November 23, 1993. The Cabinet-level council is the principal means by which the President coordinates science, space, and technology policies across the Federal Government. NSTC coordinates the diverse parts of the Federal research and development enterprise. An important objective of the NSTC is the establishment of clear national goals for Federal science and technology investments in areas ranging from nanotechnology and health research to improving transportation systems and strengthening fundamental research. The Council prepares research and development strategies that are coordinated across Federal agencies to form a comprehensive investment package aimed at accomplishing multiple national goals. Please call the NSTC Executive Secretariat at 202-456-6101 to obtain additional information regarding the NSTC, or visit the NSTC website at www.ostp.gov/nstc/.

About the Office of Science and Technology Policy

The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976. OSTP's responsibilities include advising the President in policy formulation and budget development on all questions in which science and technology (S&T) are important elements; articulating the President's S&T policies and programs; and fostering strong partnerships among Federal, State, and local governments, and the scientific communities in industry and academia. The Director of OSTP also serves as Science Advisor to the President and manages the NSTC for the President. Please call 202-456-7116 to obtain additional information regarding OSTP, or visit the OSTP website at www.ostp.gov/.

About this document

The primary purpose of this document is to identify for the Federal Government environmental, health, and safety (EHS) research and information needs related to understanding and management of potential risks of engineered nanoscale materials that may be used, for example, in commercial or consumer products, medical treatments, environmental applications, and research. This document will be used by NSTC's Nanoscale Science, Engineering, and Technology (NSET) Subcommittee and Federal agencies to inform and guide research programs. It also communicates to various nongovernment stakeholders approaches for obtaining the knowledge and understanding necessary to enable risk assessment and management of nanomaterials. Industry producers and users of nanomaterials, for example, may use this document to inform their own research, risk assessment, and risk management activities.

Cover and book design

Book design and layout by Cate Alexander and other NNCO staff members. Cover design by Nicolle Rager of Sayo-Art and Kathy Tresnak of Konzept, Inc.

Copyright information

This document is a work of the U.S. Government and is in the public domain. Subject to stipulations below, it may be distributed and copied, with acknowledgment to the National Nanotechnology Coordination Office (NNCO). Copyrights to graphics included in this document are reserved by original copyright holders or their assignees and are used here under the Government's license and by permission. Requests to use any images must be made to the provider identified in the image credits, or to the NNCO if no provider is identified.

Printed in the United States of America. 2006.

**ENVIRONMENTAL, HEALTH, AND SAFETY RESEARCH NEEDS
FOR ENGINEERED NANOSCALE MATERIALS**



September 2006

**Nanoscale Science, Engineering, and Technology Subcommittee
Committee on Technology
National Science and Technology Council**

*NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
COMMITTEE ON TECHNOLOGY (CT)
SUBCOMMITTEE ON NANOSCALE SCIENCE, ENGINEERING, AND TECHNOLOGY (NSET)*

CT Co-Chairs: Richard Russell, Associate Director, Office of Science and Technology Policy (OSTP)
Robert Cresanti, Under Secretary of Commerce for Technology

CT Executive Secretary: Anne Chaka, National Institute of Standards and Technology

NSET Subcommittee Agency Co-Chair Altat Carim	National Nanotechnology Coordination Office Director Clayton Teague
NSET Subcommittee OSTP Co-Chair Celia Merzbacher	NSET Subcommittee Executive Secretary James Murday

Department and Agency Representatives

Office of Science and Technology Policy (OSTP) Celia Merzbacher	Department of Justice (DOJ) Stanley Erickson	National Aeronautics and Space Administration (NASA) Minoo Dastoor Murray Hirschbein
Office of Management and Budget (OMB) Irene Brahmakulam	Department of Labor (DOL) Brad Wiggins	National Institutes of Health (NIH/DHHS) Gregory Downing Eleni Kousvelari Peter Moy Jeffery Schloss
Bureau of Industry and Security (BIS/DOC) Kelly Gardner	Department of State (DOS) George Atkinson Ralph Braibanti Christopher Rothfuss	National Institute for Occupational Safety and Health (NIOSH/CDC/DHHS) Vladimir Murashov
Consumer Product Safety Commission (CPSC) Mary Ann Danello Trey Thomas	Department of Transportation (DOT) Richard John Annalynn Lacombe Richard Livingston	National Institute of Standards and Technology (NIST/DOC) Michael Postek Robert Shull
Cooperative State Research, Education and Extension Service (CSREES/USDA) Hongda Chen	Department of Treasury (DOTreas) John Bobalek	National Science Foundation (NSF) Lance Haworth Maryanna Henkart Mihail Roco James Rudd
Department of Defense (DOD) William Berry David Stepp Mihail Gross James Murday Gernot Pomrenke	Environmental Protection Agency (EPA) Barbara Karn Stephen Lingle Nora Savage Philip Sayre	Nuclear Regulatory Commission (NRC) Michele Evans
Department of Education (DOEd) Richard LaPointe Sharon Lee Miller	Food and Drug Administration (FDA) Norris Alderson Stanley Brown Richard Canady	Technology Administration (TA/DOC) Connie Chang John Sargent
Department of Energy (DOE) Kristin Bennett Altat Carim Patricia Dehmer Sara Dillich Aravinda Kini John Miller Brian Valentine	Forest Service (FS/USDA) Christopher Risbrudt Theodore Wegner	U.S. Patent and Trademark Office (USPTO/DOC) Charles Elishway Bruce Kisliuk
Department of Homeland Security (DHS) Eric Houser Richard Lareau Keith Ward	Intelligence Technology Innovation Center (ITIC) Susan Durham	
	International Trade Commission (ITC) Elizabeth Nesbitt	

Report prepared by
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
COMMITTEE ON TECHNOLOGY (CT)
SUBCOMMITTEE ON NANOSCALE SCIENCE, ENGINEERING, AND TECHNOLOGY (NSET)
NANOTECHNOLOGY ENVIRONMENTAL AND HEALTH IMPLICATIONS (NEHI) WORKING GROUP

NEHI Working Group Chair: Norris Alderson

Department and Agency Representatives

Office of Science and Technology Policy (OSTP)	Department of Transportation (DOT)	National Institute for Occupational Safety and Health (NIOSH/CDC/DHHS)
Celia Merzbacher	William Chernicoff	Paul Middendorf
Kevin Geiss		Vladimir Murashov
Office of Management and Budget (OMB)	Environmental Protection Agency (EPA)	National Institute of Standards and Technology (NIST/DOC)
Nancy Beck	Flora Chow	Dianne Poster
Keith Belton	Kevin Dreher	John Small
John Kraemer	Jeremiah Duncan	
Margaret Malanoski	Stephen Lingle	National Nanotechnology Coordination Office (NNCO)
	Nora Savage	E. Clayton Teague
Consumer Product Safety Commission (CPSC)	Philip Sayre	Cate Alexander
Mary Ann Danello		Philip Lippel
Trey Thomas	Food and Drug Administration (FDA)	
	Norris Alderson	National Science Foundation (NSF)
Cooperative State Research, Education and Extension Service (CSREES/USDA)	Robert Bronaugh	Enriqueta Barrera
Monte Johnson	Stanley Brown	Cynthia Ekstein
	Richard Canady	Lynn Preston
Department of Defense (DOD)	International Trade Commission (ITC)	Mihail Roco
Randy Cramer	Elizabeth Nesbitt	James Rudd
David Sheets		
	National Aeronautics and Space Administration (NASA)	Occupational Safety and Health Administration (OSHA)
Department of Energy (DOE)	Minoo Dastoor	William Perry
Jay Larson		Val Schaeffer
John Miller	National Institutes of Health (NIH/DHHS)	Loretta Schuman
Ken Rivera	Travis Earles	
Paul Wambach	Scott McNeil	U.S. Geological Survey (USGS)
	Sally Tinkle	Sarah Gerould
Department of State (DOS)	Nigel Walker	Steven Goodbred
Christopher Rothfuss		

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20502

September 20, 2006

Dear Colleague:

Important scientific and technological advances based on understanding and control of properties and processes at the scale of atoms and molecules—the nanometer scale—are taking place in laboratories around the world. The ability to control materials at the nanoscale is already leading to novel materials and improved performance and other characteristics in existing products. Over the longer term, nanotechnology promises even more revolutionary advances with potential impacts on nearly every industrial sector, including energy, health care, defense, transportation, and electronics. The novelty of nanoscale materials arises from the fact that with decreasing size, the properties of materials change. Such changes, however, may be accompanied in some cases by increased environmental, health, and safety risks.

This report identifies the research and information needed in order to enable sound risk assessment and risk management of nanoscale materials and the products that incorporate them. It was prepared by the Nanotechnology Environmental and Health Implications Working Group under the National Science and Technology Council's Nanoscale Science, Engineering, and Technology Subcommittee. Its primary purpose is to inform Federal agencies that support nanotechnology research to guide planning, management, and coordination of nanotechnology-related environmental health and safety research. These efforts will also support agencies responsible for protecting public health, workers, consumers, and the environment, and guide other stakeholders, including manufacturers and users of nanoscale materials, in their own health and safety activities.

The National Nanotechnology Initiative (NNI) has recognized the need to understand the potential health and environmental effects of nanoscale materials and has funded research in this area since its inception. In Fiscal Year 2007, the President's Budget requests \$44 million for research that is aimed primarily at understanding and addressing the potential risks to health and the environment posed by nanotechnology. In addition, the NNI funds significant research into the development of instruments and methods for characterizing nanoscale materials and processes that are critical to the ability to perform accurate health and safety testing.

Today, the United States leads the world not only in spending for nanotechnology development but also, by an even larger margin, in its investment in research to understand the potential health and safety issues. Continued strong interagency coordination of the Federal Government's investment in both aspects of this emerging technology will help ensure full realization of the potential of nanotechnology in a safe and responsible manner.

Sincerely,



John H. Marburger, III
Director

TABLE OF CONTENTS

Table of Contents	i
Executive Summary	iii
1. Introduction	1
Background to This Document	1
Risk Assessment and Risk Management	2
Federal Nanotechnology EHS Research	4
Document Development	5
The Purpose of This Document	8
Principles for Identifying and Prioritizing EHS Research	9
Next Steps	10
2. Instrumentation, Metrology, and Analytical Methods	11
Terminology, Nomenclature, and Standards Development for Engineered Nanoscale Materials	11
Analytical Tools and Methods	12
3. Nanomaterials and Human Health	19
Biological Response	19
Exposure: Routes and Measurement	24
4. Nanomaterials and the Environment	29
Environmental Hazard Characterization	29
Environmental Transport and Fate	29
5. Health and Environmental Surveillance	35
Occupational Health and Exposure	35
Public Health and Exposure Surveillance	37
Environmental Health Surveillance	39
6. Risk Management Methods	43
Risk Management Approaches	43
Reducing Exposure in the Workplace	45
Minimizing Environmental Exposure and Hazard	48
Life Cycle Assessment	52
Risk Communication Methods	55
Glossary	57
References	59

EXECUTIVE SUMMARY

Scientific and engineering advances in the understanding and control of matter at the scale of 1–100 nanometers (nm) are the realm of “nanotechnology.” Within this realm is the potential for achieving significant practical benefits in applications areas ranging from energy and electronics to medicine and agriculture. The range and magnitude of possibilities that emerge from the ability to design and manufacture materials and increasingly complex structures and devices at the scale of atoms and molecules is great, leading many to believe that nanotechnology may revolutionize technology as we know it. At the nanoscale material properties vary as a function of size, which not only enables new benefits, but also may lead to unintended health and environmental risks. This document provides a description of the research needed in order to identify and address potential risks from the application and use of nanotechnology.

The Federal Government’s nanotechnology research programs, in general, fall under the National Nanotechnology Initiative (NNI). Coordination of research in the field takes place through the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the National Science and Technology Council.

In order to support Federal activities to protect public health and the environment, in 2003 the NSET Subcommittee created the Nanotechnology Environmental and Health Implications (NEHI) Working Group with the purpose, among other things, of facilitating the identification, prioritization, and implementation of research and other activities required for the responsible research, development, utilization, and oversight of nanotechnology.

This document reflects the efforts of the NEHI Working Group to begin this facilitation process and, specifically, to describe the environmental, health, and safety (EHS) research and information needed to enable sound risk assessment and risk management decision making. The document has been produced collaboratively by the Federal agencies that participate in the NNI and has been informed by recommendations from industry liaison groups and by other reports and documents on EHS research needs.

The primary purpose of this document is to identify for the Federal Government the EHS research and information needs related to understanding and management of potential risks of engineered nanoscale materials that may be used in commercial or consumer products, medical treatments, environmental applications, research, or elsewhere. In addition, industry producers and users of engineered nanoscale materials may use this document to inform their own research, risk assessment, and risk management activities. Through this publication, the NSET Subcommittee communicates to various nongovernmental stakeholders the research needs and approaches that it has identified for obtaining the knowledge and understanding necessary to enable risk assessment and management of engineered nanoscale materials.

The NSET Subcommittee and Federal agencies will use this document to inform and guide individual and joint research programs. The next steps toward addressing the research needs described in this document include further prioritization among the needs identified in the document, evaluating in greater detail the NNI EHS research portfolio, determining gaps between identified research needs and the research already underway, coordinating and facilitating among NNI agencies’ research programs to address outstanding priorities, and establishing a process for periodic review of progress for updating research needs and priorities. The NSET Subcommittee will seek stakeholder input regarding strategic and interim goals for filling the EHS information needs and gaps for engineered nanoscale materials.

This document addresses EHS research needs associated only with engineered nanoscale materials. It does not address nanoscale materials that are naturally occurring or are incidental byproducts of

manufacturing, combustion, or other human processes. However, the substantial body of knowledge about risks related to exposures to these other categories of nanoscale materials will inform risk assessment and management for engineered nanoscale materials.

That a new technology potentially could offer both benefits and, at the same time, potential risk is not unique to nanotechnology, but rather is a phenomenon associated with many new technologies. Even existing technologies and products have associated risks; two common examples are electricity and medical X-rays. Learning more about risks of technologies allows for their successful management and the realization of their benefits.

Key Document Terms

Engineered nanoscale materials, or nanomaterials, are those that have been purposefully manufactured or synthesized to have a size with at least one dimension in the range of approximately 1–100 nm and that exhibit unique properties determined by this size.

In this document, when the term “nanomaterials” is used alone, it refers to engineered nanoscale materials.

The acronym “EHS” will be used in this document as shorthand for the collection of fields associated with the terms “environmental health, human health, animal health, and safety” when used in the context of risk assessment and risk management. While a variety of acronyms derived from permutations of the terms environment, health, and safety exist in the scientific and public health policy literature, “EHS” within this document has just one interpretation, as stated above.

The contextual framework for this document, including an overview of nanotechnology and risk characterization, is provided in Chapter 1. This chapter includes a discussion of the principles for identifying and prioritizing nanomaterials EHS research so as to optimize the usefulness of research results. The chapter also describes how this document fits into the overall process by which the NSET Subcommittee is coordinating nanomaterials EHS research and describes the next steps for prioritizing, addressing, and updating the research needs.

Chapters 2–6 each address specific areas of scientific investigation for assessing and managing potential EHS risks of nanomaterials. Each chapter provides detail on existing Federal activities in the area, lists a consensus opinion on the priority research needs within the area and, for most of the areas, offers informed options for future research to address the identified needs.

Descriptions of the five general research areas identified by the NNI agencies as necessary for evaluating EHS issues for nanomaterials and examples of EHS research needs for each general area follow. *This document identifies priority research, but does not prioritize within or among the research categories, leaving that as a next step. The sequence of chapters does not reflect prioritization among the categories.*

Instrumentation, Metrology, and Analytical Methods

Chapter 2 describes research needs for new instrumentation and standard measurement protocols, as well as the development of reference materials and data related to the detection, characterization, and measurement of physical, chemical, and biological properties of engineered nanoscale materials in environmental and biological matrices (e.g., air, water, soil, cells, tissues, organs, organ systems, and whole organisms). Also addressed is the development of terminology, nomenclature, and standards. Identified research and information needs in this area include

- methods for detecting nanomaterials in biological matrices, the environment, and the workplace

Executive Summary

- methods for standardizing particle size and size distribution assessment
- methods and standardized tools for assessing nanomaterial shape, structure, and surface area
- an inventory of engineered nanomaterials and their uses

Nanomaterials and Human Health

Chapter 3 identifies research needed to determine the biological response to engineered nanoscale materials and their byproducts, the results of which may contribute to identifying potential adverse health effects in humans. This includes research on subcellular components, cells, tissues, organ systems, and whole organisms to determine biocompatibility and toxicity of various engineered nanoscale materials, and research to evaluate current toxicity screening tests and develop new tests as needed. Identified research and information needs in this chapter include

- understanding of the absorption and transport of nanomaterials throughout the body from different routes of exposure including oral, inhalational, dermal, and intravenous
- understanding of the properties of nanoscale materials that elicit a biological response
- identification and/or development of appropriate *in vitro* and *in vivo* assays/models to predict *in vivo* human responses to nanomaterial exposure
- methods to quantify and characterize exposure to nanomaterials in biological matrices

Nanomaterials and the Environment

Chapter 4 focuses on research aimed at identifying, understanding, and controlling the potential effects of engineered nanoscale materials on both relevant ecological receptors and the ecosystems that they occupy and research on ultimate disposition and transport of engineered nanoscale materials that leads to a better understanding of the mechanisms by which nanoscale materials enter, remain in, degrade, and are transported through environmental media. Identified research and information needs in this area include

- evaluation of testing schemes for ecological effects
- identification of factors affecting the transport of nanomaterials in the environment
- understanding of the transformation of nanomaterials under different environmental conditions

Health and Environmental Surveillance

Chapter 5 addresses research on the systematic collection, analysis, and interpretation of data obtained over time on human exposure to nanomaterials in the workplace and other indoor and outdoor environments; research to determine the presence of these materials or their byproducts in the environment; research on the determinants of exposures to support interpretation of limited or surrogate workplace and environmental data; monitoring of the health experience of individuals exposed to nanomaterials; and monitoring of outcomes in habitats impacted by nanomaterials. Identified research and information needs in this area include

- understanding of workplace processes and factors that affect exposure to nanomaterials
- quantification of nanomaterial exposure to the general population from industrial processes, consumer products, and other products containing nanomaterials
- establishment of environmental monitoring protocols

Risk Management Methods

Chapter 6 covers research on methods for risk management of nanomaterials, including research on methods to reduce exposures to potentially hazardous nanomaterials; research to improve procedures for risk and accident avoidance; research to improve work practices, engineering controls, and protective equipment; and research to develop procedures for life cycle assessment

and improved understanding of potential impacts over the full product life cycle, from raw material extraction through disposal and/or recycling. Identified research and information needs in this area include

- improved understanding of the unique challenges for process design and engineering control systems applied to airborne engineered nanoscale materials
- understanding and development of manufacturing approaches that minimize environmental impact to enable “green design” principles
- determination of the stages in a product’s life cycle that introduce potential for EHS risks
- evaluation of whether current risk communications methods are adequate for known risks and for risks that can be anticipated from currently available information

Federal Government Support for EHS Research

The NNI has recognized the importance of EHS research from its inception in 2001. Government-funded research toward understanding the EHS implications of nanomaterials generally falls into three broad areas: supporting research on fundamental properties and processes of nanomaterials that can lead to the understanding of broad classes of materials in various environments and applications; developing metrology tools and methods for measuring exposure to and for characterizing nanomaterials; and supporting research on toxicological properties and health effects of nanomaterials that are expected to be used widely in commerce.

Funding for nanotechnology-related EHS research has grown since it was first tracked in 2005. That year, approximately \$35 million was devoted to research whose primary purpose is to understand and address potential risks to health and the environment posed by this technology. The estimated investment in this research for 2006 is \$38 million, and the President’s 2007 budget request calls for increasing the amount to \$44 million.

In 2007, the following agencies requested funding for EHS research: National Institutes of Health (NIH), National Institute for Occupational Safety and Health (NIOSH), National Institute of Standards and Technology (NIST), Department of Defense (DOD), Environmental Protection Agency, National Science Foundation (NSF), and United States Department of Agriculture (USDA) Cooperative State Research, Education and Extension Service (CSREES). These research programs, along with other activities related to promoting the understanding of EHS implications of nanotechnology, are coordinated through the NEHI Working Group and its parent body, the NSET Subcommittee. Specifics of these programs and activities can be found in the NNI Supplement to the President’s 2007 Budget. (See www.nano.gov/NNI_07Budget.pdf.)

In addition to the Federal Government, other stakeholders are involved in this area of research. Manufacturers of nanomaterials and related products have a responsibility to test specific products for safety and to assess workplace safety and provide health surveillance. It is clear that, not only is coordination of research activities among the NNI agencies important, but also collaboration with industry and with other governments will be necessary in order to expedite progress.

Next Steps

In order to expedite progress toward addressing the research needs described in this document and to adjust those needs as development, understanding, and use of nanomaterials advance, the NSET Subcommittee—in part through the efforts of the Nanotechnology Environmental and Health Implications (NEHI) Working Group—will continue to work with the NNI agencies. To recapitulate, the next steps are to

- further prioritize research needs among those identified in this report
- evaluate in greater detail the current NNI EHS research portfolio

Executive Summary

- perform a “gap analysis” of the NNI EHS research compared to the prioritized needs
- coordinate and facilitate among the NNI agencies’ research programs to address priorities
- establish a process for periodic review of progress and for updating the research needs and priorities

Continued coordination among the agencies participating in the NNI, in consultation and collaboration with other stakeholders, will facilitate efforts toward achieving these next steps and performing the research outlined in this report. Conducting research bearing on EHS in parallel with the development of nanomaterials and their applications will help to ensure the full, safe, and responsible realization of the promise of nanotechnology.

1. INTRODUCTION

BACKGROUND TO THIS DOCUMENT

Scientific and engineering advances in the understanding and control of matter at the scale of 1-100 nanometers (nm) will likely be the foundation for achieving widespread benefits, including improved health, smarter electronics, advanced agriculture, and cleaner sources of energy. Many of the potential benefits of nanotechnology arise from the fact that engineered nanoscale materials exhibit properties and behavior different from those of the same material in bulk or macroscopic form. Some nanostructures have no bulk equivalent, but are made by forming new nanostructures by “building up” from atoms and molecules.

The magnitude of possibilities for exploiting nanotechnology is great—ranging from the ability to design and manufacture materials at the scale of atoms and molecules to the development of increasingly sophisticated active structures, devices, and systems. These possibilities lead many to believe that nanotechnology may revolutionize technology as we know it. At the nanoscale, material properties vary as a function of size, which not only enables new benefits, but also may lead to unintended health and environmental risks. This document provides a description of research needed in order to identify and address potential risks from the development of nanotechnology.

The chemical, physical, and biological properties of nanomaterials may differ from those of the same materials in bulk or in micrometer or greater size ranges. For example, gold, which is valued for its inert properties at the macroscale, becomes highly reactive when prepared as 3 nm particles; and many bulk semiconductor materials are very poor light emitters, but semiconductor “quantum dots” of different sizes in the nanometer range can be made to fluoresce brilliantly in various colors, depending on their size.

In addition to nanoscale versions of existing materials, entirely new classes of materials, such as new forms of carbon, called fullerenes, have been developed, offering unique sets of properties. The most familiar of these are carbon spheres known as C_{60} , also called buckyballs, and their elongated siblings, carbon nanotubes. Carbon nanotubes are among the strongest materials known. They can exhibit nonconductive, semiconductive, or metallic electronic properties, depending on their structural configuration.

The novel properties of nanomaterials have contributed to developments in diverse application areas, such as medical imaging, catalysis, and solid state lighting. Products on the market today are enabled by nanomaterials, including stain-resistant clothing and glare-resistant sunglasses. Although researchers envision complex devices made of nanoscale components with novel capabilities, at present most products offer modest improvements in performance by incorporating nanomaterials.

Scientific understanding of how engineered nanoscale materials of various compositions interact with biological systems is incomplete. In addition, there are fundamental questions that research must address about how to best assess the impacts of nanomaterials. Questions include: Are current toxicity testing methods appropriate for assessing the toxicity and potential biological effects of engineered nanoscale materials? How do chemical/physical properties of those nanomaterials relate to their elicited biological responses? What kinds of human and environmental exposures to nanomaterials can be anticipated and measured? By which paths do nanomaterials move within the body? Are there any special considerations for the measurements of nanomaterials?

These and more specific research questions are discussed in this document. The research itself is expected to be funded by governments, including the U.S. Government, and by non-governmental

1. Introduction

institutions, both academic and industrial. The U.S. Government research will take place within the framework of the National Nanotechnology Initiative (NNI) Strategic Plan, set out in 2004 (see www.nano.gov/NNI_Strategic_Plan_2004.pdf).

As research—both publicly and privately supported—on applications of nanomaterials continues to expand, it is important to carry out the research that will enable well-informed risk assessment. It is incumbent upon those responsible for managing product and process risks and for protecting human and environmental health to utilize available information to assess risk. Where information is not available, it is important that experts in the fields—e.g., manufacturers, regulators, standards developers, research agencies and institutions—identify the types of information and research that are needed and to fill any gaps that exist. Sharing of data and collaboration on research—to the extent that it does not compromise proprietary information—should be a goal for both government and industry.

Notes on Terminology

The rapid pace of discovery related to nanomaterials and nanoscale processes is in some cases ahead of the systems of agreed-upon terminology and nomenclature for other materials used in research and manufacturing, which do not generally consider size as a criterion. For parties who are describing nanomaterials for the purposes of research or commerce, as well as for those who are responsible for establishing procedures and limits for safe use of engineered nanoscale materials, the creation of widely accepted terminology is essential.

For better understanding of terms used in this document, the following definitions are provided:

Engineered nanoscale materials, or nanomaterials, are those that have been purposefully manufactured or synthesized to have a size with at least one dimension in the range of approximately 1-100 nm and that exhibit unique properties determined by this size.

In this document, the term “nanomaterials” used alone will be shorthand for engineered nanoscale materials.

The acronym “EHS” will be used in this document as shorthand for the collection of fields associated with the terms “environmental health, human health, animal health, and safety” when used in the context of risk assessment and risk management. While a variety of acronyms derived from permutations of the terms environment, health, and safety exist in the scientific and public health policy literature, “EHS” within this document has just one interpretation, as stated above.

RISK ASSESSMENT AND RISK MANAGEMENT

Many beneficial technologies and products have associated risks that are successfully managed, for example, gasoline, electricity, and medical X-rays. In general, risk of harmful effects attributable to chemicals, materials, or other products is a function of hazard and exposure in combination; that is, risk occurs only where the material is hazardous and exposure is quantitatively sufficient for biological response. Risk assessment is a process by which information is analyzed in a rational framework to determine the likelihood that a substance will cause harm to exposed persons or ecosystems (NRC, 1983). Risk assessments are conducted to provide the best possible scientific characterization of risks based on a rigorous analysis of available information and knowledge. In order to assess risk, it is necessary to identify and characterize possible hazards and to estimate the likelihood and magnitude of exposure.

Hazards can be defined as those materials or processes that produce toxic effects in humans or in the environment, or that have other potential adverse effects, such as causing fires or explosions. Hazards can be classified in terms of harm posed to living organisms—such as humans, wildlife,

1. Introduction

and vegetation—and ecosystems. In human health, hazards can be associated with transient biological response, such as irritation to the skin or eyes, or with serious systemic and persistent health effects such as organ impairment or failure. The characterization of hazards includes quantification of toxicity through testing and determination of specific biological response as a result of interaction with a compound of interest. This approach is not unique to nanomaterials; many or most of these processes would be equally applicable to materials emerging from any new technology.

It is expected that exposure potential for some nanomaterials will be very limited to nonexistent, whereas exposure potential for other materials will exist at one or more stages of their product life cycles. Research on potential exposure must evaluate whether, and to what degree, exposure will occur for each nanomaterial at each stage of its life cycle. Characterization of exposure involves methods and tools for measuring materials in various media and organisms. One approach, an initial life cycle screening approach, may be useful to express the range of exposure likelihoods and potential areas of focus for research across the life cycle for products containing nanomaterials. For example, using a matrix approach, it would be possible to express the likelihood of exposure for key segments of the population (i.e., worker, consumer, patient, and the general public) across stages covering the life cycle of the nanomaterial from research and development to manufacture, distribution, use, and disposal (see Table 1 below). Each population segment/product stage combination then could be evaluated for exposure risks (e.g., inhalation, intravenous, dermal contact, eye exposure, and oral ingestion).

Hazard and exposure are linked by dosimetry—i.e., measurement of the amount of material in the body or the environment. Risk characterization, the last step in risk assessment and the starting point for risk management, includes a summary of key conclusions from the hazard, exposure, and dose components of the risk assessment and documentation of all supporting evidence. Risk characterization includes a description of the nature and likelihood of the risk, identification of individuals or groups at risk, the severity of the anticipated effects, the strength of the evidence supporting the conclusions of risk, uncertainty about the nature or magnitude of the risk, and other

Potential Recipient of Exposure	Product Life Cycle Stage				
	Research and Development	Manufacture	Processing/Distribution	Use	Disposal
Worker	Inhalation: Oral: Dermal:	Inhalation: Oral: Dermal:	Inhalation: Oral: Dermal:	Inhalation: Oral: Dermal:	Inhalation: Oral: Dermal:
Consumer	NA	NA	Inhalation: Oral: Dermal:	Inhalation: Oral: Dermal:	Inhalation: Oral: Dermal:
Public (non-consumer)	Inhalation: Oral: Dermal:	Inhalation: Oral: Dermal:	Inhalation: Oral: Dermal:	Inhalation: Oral: Dermal:	Inhalation: Oral: Dermal:
Environmental Release	Water: Soil: Air:	Water: Soil: Air:	Water: Soil: Air:	Water: Soil: Air:	Water: Soil: Air:

Table 1. One way of organizing exposure and life cycle information is in a matrix, such as that above. In this matrix, research needs at various stages of a product's life cycle and research findings, when available, can be tracked by exposure route and by the potential recipient of the exposure.

1. Introduction

relevant factors, including range of expert opinion regarding key elements of the risk assessment and the relationship between effects caused by the exposure and background rates of those effects (Presidential/Congressional Commission on Risk Assessment and Risk Management, 1997).

Risks posed by nanomaterials, like risks posed by chemicals, cannot be easily generalized. Both hazard and exposure potential will vary widely for different nanomaterials and for different products or applications that incorporate nanomaterials. However, further research may enable nanomaterials to be grouped according to certain structures and compositions and their potential for risk as a group to be generalized. In the meantime, risk assessments must be made in the face of considerable uncertainty and on a case-by-case basis. Tiered testing approaches to risk assessment that integrate both effects and exposure considerations for nanomaterials may be appropriate (Oberdörster et al., 2005a). Increasing computational capabilities could enable the modeling and possibly the prediction of biological responses to nanomaterials. Further, collaboration and multidisciplinary approaches may speed the development of knowledge for proper sample handling and processing.

Where nanomaterials are incorporated into products, such as computer circuit boards, the potential for exposure during use is unlikely because nanomaterials are effectively embedded in the product matrix. Although products containing embedded materials may have less risk for consumers, potential exposure of workers involved in the manufacture of such materials must still be considered, as well as potential exposure of workers, the general public, or the environment during recycling or disposal at the end of product life. Predicting the risk of nanomaterials, therefore, includes conducting research, developing protocols, and gathering data to evaluate nanomaterial products over their lifetimes and assessing when, where, and how exposure to humans or ecosystems could occur.

Good risk assessment is essential for good risk management. Following identification of a risk, risk managers can evaluate options for addressing the risk and make informed decisions that reduce or avoid the risk. Options include replacing a hazardous material or process with a less hazardous one (in some cases, a nanomaterial may be able to reduce the use of known hazardous materials), using engineering controls to minimize exposures in the workplace, and following specific protocols for medical therapies so as to minimize undesirable side effects in patients. Life cycle assessment studies may be used to identify opportunities for risk management through materials selection, product design, manufacturing process engineering, or recycling to reduce potential risks or adverse impacts at any of the stages.

FEDERAL NANOTECHNOLOGY EHS RESEARCH

The NNI has recognized the importance of environmental, health, and safety (EHS) research from its inception in 2001. Accordingly, the Federal Government supports research that will allow new products resulting from nanoscience to be introduced and used safely.

Government-funded research toward understanding the EHS impacts of nanomaterials generally falls into three broad areas. They include basic and applied research (1) to expand knowledge and further the understanding of how nanomaterials behave, including in the environment and in the human body; (2) to develop instrumentation and methods for measuring, characterizing, and testing nanomaterials and for monitoring exposure; and (3) to contribute to safety assessments of nanomaterials and nanomaterial-based products.

During fiscal year 2003, the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the National Science and Technology Council (NSTC) Committee on Technology established the Nanotechnology Environmental and Health Implications (NEHI)

1. Introduction

Working Group to promote dialogue among the Federal agencies in the field of EHS research. In fiscal year 2005, the NEHI Working Group was formally chartered to

- provide for exchange of information among agencies that support nanotechnology research and those responsible for regulation and guidelines related to nanomaterials
- facilitate the identification, prioritization, and implementation of research and other activities required for the responsible development, utilization, and oversight of nanotechnology, including research methods for life cycle analysis
- promote communication of information related to research on environmental and health implications of nanotechnology to other government agencies and non-government parties

The NNI agencies have funded EHS research since 2001. In 2005, approximately \$35 million was devoted to research whose primary purpose is to understand and address potential risks to health and the environment posed by this technology. The estimated investment in this research for 2006 is \$38 million, and the President's 2007 budget request calls for increasing the amount to \$44 million. Developing a fundamental body of knowledge, creating specialized research facilities, and sponsoring programs for education and training people in EHS research are essential elements of the NNI efforts in EHS. NSF has played a large role in all three of these areas of EHS research since the inception of the NNI. Due to the increased awareness that the understanding of nanomaterial toxicology and other related fields of study will improve only with more basic research and instrumentation and metrology development, NNI investment reports in the future will provide more detail about the funding in each of the areas covered in this document.

Top strategic priorities of the NNI agencies include support for research and development leading to a detailed understanding of the health and safety impacts of nanotechnology for researchers, workers, consumers, and the public and of the environmental impacts of various applications of nanotechnologies. For 2007, seven NNI agencies requested funding for such R&D, including National Institutes of Health (NIH), National Institute for Occupational Safety and Health (NIOSH), National Institute of Standards and Technology (NIST), Department of Defense (DOD), Environmental Protection Agency, National Science Foundation (NSF), and United States Department of Agriculture (USDA) Cooperative State Research, Education and Extension Service (CSREES). All of these agencies and 9 others participate in the NEHI Working Group.

Exchange and coordination of information related to risk assessment of nanotechnology products takes place through participation in the NEHI Working Group. Further, numerous interagency collaborations on EHS research are the result of interaction through the NSET Subcommittee and NEHI Working Group. Specifics of these collaborations can be found in the NNI Supplement to the President's 2007 Budget (see www.nano.gov/NNI_07Budget.pdf).

DOCUMENT DEVELOPMENT

The NEHI Working Group was created by the NSET Subcommittee in 2003 with the purpose, among other things, of facilitating the identification, prioritization, and implementation of research and other activities required for the responsible research, development, utilization, and oversight of nanotechnology. This document reflects the efforts of the NEHI Working Group to begin this facilitation process and, specifically, to describe the EHS research and information needed to enable sound risk assessment and risk management.

The research needs were identified in a process that involved direct inputs from the Federal agencies that regulate and/or conduct research in nanotechnology, and other inputs as described in the following sections. Input from the regulatory agencies was particularly important, in that it identified research needs related to risk assessment and management of nanomaterials in view of

the various regulatory authorities. As such, the document will be an integral part of the interagency process by which Federal nanotechnology EHS research is coordinated.

Also contributing greatly to the preparation of this document was early work by the NEHI Working Group on nanotechnology risk assessment issues. Expertise from Working Group members, along with input from other experts, was used to develop an influence diagram that described the main inputs needed to conduct nanomaterial risk assessments (Morgan, 2005). The influence diagrams (see Figure 1 below for the top-level diagram) describe the system of variables that experts hypothesized might influence hazard. This decision diagram identifies potential areas of research that might be needed to understand whether, how, and to what degree these variables relate to hazard. The Morgan (2005) influence diagram illustrates the complexity in this undertaking by showing the system of information that experts, including the NEHI Working Group members, hypothesized might be needed to conduct a risk assessment.

The five research areas described in Chapters 2–6 of this document reflect the general areas of research identified by the agencies as necessary for evaluating environmental, health, and safety issues for nanomaterials. *The order of the chapters in which these areas are presented is not intended to reflect prioritization.* Each chapter includes a brief description of the topic and its relevance to understanding EHS effects of nanotechnology, summaries of existing Federal research efforts, identification of primary needs for research and information, and, in most cases, suggestions for possible approaches that will build on current research and research directions.

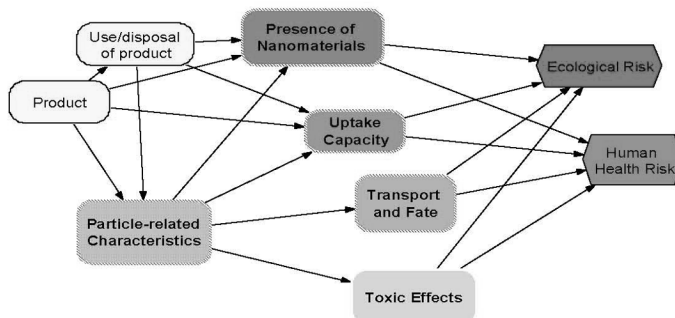


Figure 1. Influence Diagram for Nanomaterial Properties Relevant to Evaluation of Hazard. Each box in this figure represents a module that contains a system of variables. The detail contained within each module is shown in nested subdiagrams that are described in Morgan (2005). The rounded boxes are variables and the hexagon-shaped boxes are the areas of focus. The arrows indicate hypothesized influence, so that an arrow from variable 1 to variable 2 means that variable 1 is hypothesized to influence variable 2. All the variables have some hypothesized influence, either direct or indirect, on the focus areas. For more information, see Morgan (2005).

1. Introduction

Other Nanotechnology EHS Research Needs Documents

A number of reports have offered informed opinions regarding research needed to properly assess and manage nanotechnology-related risks and benefits to health and the environment. These reports, from a variety of stakeholders, including government agencies, commercial entities, and academia, were reviewed in the preparation of this document. The rapid development of publications on this issue makes any such collection almost certainly incomplete. However, in general, these documents are in agreement regarding potential for risk from at least some nanomaterial applications and that research is needed to improve those risk assessments and to enable appropriate risk management. Development of this document has been informed by many of those reports, which are listed in the references section of this publication.

A few resource documents deserve special attention in this discussion. One is that developed by representatives from the chemical and semiconductor industries in consultation with Government agencies. Their report, *Joint NNI-Chemical Industry Consultative Board for Advancing Nanotechnology and Semiconductor Research Council CWG5: Nanotechnology Research Needs Recommendations* (Joint Chemical Industry Consultative Board for Advancing Nanotechnology, 2006), outlines those industries' priorities for government research in EHS related to nanotechnology.

Another document of particular value in preparing this document was the Environmental Protection Agency (EPA) *Nanotechnology White Paper* (U.S. EPA, 2005), which was released in draft form for public comment in December 2005. This paper identifies and describes the issues EPA must address to ensure protection of human health and the environment as this new technology is developed. The draft white paper addresses risk assessment and management issues and the agency's statutory mandates. It identifies research needs for both environmental applications and implications of nanotechnology and concludes with recommendations on next steps for addressing science policy issues and research needs.

Also providing valuable information for this document was the National Institute for Occupational Safety and Health (NIOSH) and its recent publications, including *Approaches to Safe Nanotechnology: An Information Exchange with NIOSH* (NIOSH, 2005a), a draft guidance and discussion document that outlines current knowledge about the occupational health and safety implications and applications of engineered nanoscale materials, using internal and external research data. This NIOSH document also offers interim recommendations on occupational safety and health practices in the production and use of nanomaterials, including mitigation of potential workplace exposures. These interim recommendations will be updated and revised as newer data become available. In addition, the *Strategic Plan for NIOSH Nanotechnology Research: Filling the Knowledge Gaps* describes a timely, multidimensional research agenda for NIOSH and its research partners to lead the occupational safety and health community collaboratively in nanotechnology research. (See these and other NIOSH documents at the NIOSH nanotechnology website, www.cdc.gov/niosh/topics/nanotech/.)

Internationally, the white paper prepared by the Royal Society/Royal Academy of Engineering (RS, RAEng) in the United Kingdom, *Nanoscience and Nanotechnologies: Opportunities and Uncertainties*, provided a comprehensive look at emerging nanotechnologies, including benefits and potential risks (RS, RAEng, 2004). Noting that nanomaterials take many forms (e.g., particles, tubes), the report addressed concerns over potential environmental and health risks of nanomaterials. Following the publication of the RS, RAEng report, the British government commissioned two studies to explore hazard and exposure data needs (Tran et al., 2005; Mark et al., 2005). At the same time, the European Commission funded a separate study led by the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) to examine the efficacy of current risk assessment methodologies on nanomaterials (EC-SCENIHR, 2006). This

1. Introduction

report identifies eight research needs (or “critical knowledge gaps”) requiring attention for risk assessment.

The research recommended in existing reports for scientifically based risk assessment varies in certain details but, in general, is well aligned. All of the reports reviewed for this document recognize that the greatest exposure potential to humans and the environment from nanomaterials would come from those that are “free” or not otherwise integrated as elements of larger materials. The reports stress the need for research in the following areas: nanomaterial characterization, methods for identifying hazards, understanding biological response to nanomaterials, and characterizing nanomaterial exposure and transport (in humans and the environment). In support of these efforts, the reports also call for common nomenclature to classify nanoscale particles and effectively communicate results. There is less agreement with respect to which research areas deserve highest priority (e.g., exposure vs. hazard identification). *This document identifies priority research, but does not prioritize within or among the research categories.*

THE PURPOSE OF THIS DOCUMENT

The primary purpose of this document is to identify for the Federal Government the environmental, health, and safety research and information needs related to understanding and managing the potential risks of engineered nanoscale materials that may be used in commercial or consumer products, medical treatments, environmental applications, and research.

This document will be used by the NSET Subcommittee and Federal agencies to inform and guide research programs. It also communicates to various non-government stakeholders approaches for obtaining the knowledge and understanding necessary to enable risk assessment and management of nanomaterials. Industry producers and users of nanomaterials, for example, may use this document to inform their own research, risk assessment, and risk management activities.

The Federal Government, through its agencies, implements various statutes and regulations to ensure that the risks of products are appropriately and adequately managed. Information regarding the risks and benefits of nanomaterials will be utilized by regulatory bodies that are responsible for protecting public health and the environment.

EHS research, which will increase the understanding of risks and benefits of nanomaterials, is supported by various stakeholders, including the U.S. Government, other governments, and industry. Federal funding of such research is intended to increase general understanding of risks and benefits of nanomaterials and to provide the scientific basis for regulatory decision making for materials and products. Federal funding also supports development of tools and methods for characterization and measurement that are fundamental to risk assessment and management. Manufacturers generally carry out research to determine safety of their products and in some cases are required to provide scientific data for regulatory decision making by the government.

By outlining the spectrum of research needs, the NNI agencies expect to accelerate progress toward comprehensive understanding of the risks and benefits for various types of nanomaterials. The knowledge gained from subsequent research will allow potential risks to be avoided or appropriately minimized during application and product development, and to be managed where the advantages of specific materials make such steps worthwhile. The information also can lead to pollution prevention benefits where the potential risks and impacts of nanomaterials are less than those of conventional materials. This document addresses the NNI agencies’ current best understanding of the research and information needs for the assessment of EHS issues associated with *engineered nanoscale materials*, defined as nanomaterials that are intentionally designed and produced. This document does not directly address risk assessment of nanomaterials that occur *naturally* or are produced by physical or biological processes such as dust from deserts or from

1. Introduction

shell abrasion. The document also does not address nanoscale materials that are *incidental* byproducts, i.e., unintentionally produced from manufacturing or other processes such as welding or combustion. However, it is clear that the substantial body of knowledge related to exposures to these other categories of nanoscale materials (such as diesel exhaust, welding fumes, and ambient dusts) will inform risk assessment for engineered nanoscale materials (U.S. EPA, 2004 and 2006).

PRINCIPLES FOR IDENTIFYING AND PRIORITIZING EHS RESEARCH

At this early stage in the development of nanomaterials and their applications, it is useful to establish principles for identifying and prioritizing EHS research needs. Application of such principles allows for more efficient advancement in understanding the properties, behaviors, and potential risks of nanomaterials and more productive use of available resources. The NSET Subcommittee, through its NEHI Working Group, has created the following principles as guidelines to help researchers, program managers, and policy makers prioritize EHS research and investment.

1. Prioritize research based on the value of information. This is the overarching principle from which all of the subsequent principles flow. The value of any particular piece or set of data or information for assessing risks of a given nanomaterial depends directly on various factors, including

- The extent to which the information will reduce uncertainty about benefits or risks. Key uncertainties need to be identified and evaluated, accounting for both the likelihood of health or environmental risk and the magnitude of benefit from a specific application. Similarly, reducing uncertainty for nanomaterials will enable safer manufacture, use, and disposal.
- The extent to which information can be expected to lead to broad knowledge about the properties and behavior of nanomaterials or classes of nanomaterials more generally. For example, certain computational tools may be especially powerful and cost effective in enabling materials to be designed to achieve the desired properties while reducing toxicity.
- The extent of use expected for the nanomaterial. With the plethora of nanomaterials being developed in laboratories, it is necessary to identify for toxicological study—which is time consuming and costly—those materials that are likely to be used in multiple products or processes.
- The exposure potential for workers, consumers, or the environment to the nanomaterial being used in or developed for applications.
- The potential to leverage relevant existing data. In the case of nanoscale materials, there is an extensive body of existing research on incidental nanoscale materials—for example, diesel exhaust—that will inform the identification and prioritization of research and information needs for nanomaterials. (In turn, research results for nanomaterials will aid in understanding the sometimes more complex problems due to variability in size and composition for incidental and naturally occurring nanoscale materials.)

In the broad area of applications development, research that integrates toxicological or risk assessment of nanomaterials as part of their design or engineering would be extremely valuable and would increase the likelihood of producing materials that are environmentally and biologically compatible.

2. Leverage international and private sector research efforts. Although the United States is a world leader in nanotechnology R&D, approximately 75 percent of the research investment worldwide is provided by other nations or regions. Moreover, the total R&D spending by the private sector now equals or exceeds the combined government investment. It is not surprising, therefore, that the need for EHS research related to nanotechnology is a global concern. Research

1. Introduction

directed at understanding EHS issues benefits nations that produce nanotechnology-enabled products, as well as those who use them. Redundancy in research can be avoided and resources used more effectively through cooperative efforts at the international level. Resources can be leveraged through joint calls for proposals, workshops, data sharing, bilateral engagement, and other international activities, such as those of the Organisation for Economic Co-operation and Development (OECD) and the International Dialogue for the Responsible Research and Development of Nanotechnology, co-sponsored by NSF and several other international governmental bodies.

3. Use adaptive management for nanomaterial EHS research. New developments in nanomaterials are advancing rapidly and can be expected to continue to do so in the coming years. In order to expedite development of information that enables both protection and beneficial applications for human health and the environment, it is important to adapt research strategies in accordance with emerging R&D directions. Agency funding decisions for EHS research should be similarly flexible to avoid missed opportunities and to remain focused on research with the greatest value.

NEXT STEPS

In order to expedite progress toward addressing the research needs described in this document and to adjust those needs as development, understanding, and use of nanomaterials advance, the NSET Subcommittee—in part through the efforts of the Nanotechnology Environmental and Health Implications (NEHI) Working Group—will work with the NNI agencies to

- Establish research priorities. Priorities will be evaluated further, based primarily on the principles outlined above. Other factors that will be considered include the time frame for developing the information—because certain studies are inherently lengthy—and the availability of research tools.
- Evaluate in greater detail the current NNI EHS research portfolio.
- Perform a “gap analysis” of the NNI EHS research compared to the prioritized needs.
- Coordinate and facilitate among the NNI agencies’ research programs to address priorities. Agencies will work individually and jointly, where possible, to address research needs.
- Establish a process for periodic review of progress and for updating the research needs and priorities. Such a review must take into consideration advances made by entities other than U.S. Government-funded bodies, such as advances by the private sector and other governments.

Given the number of entities that will contribute to knowledge about nanomaterials and their impacts, collaboration among the various research groups is important. Furthermore, discourse among the multiple stakeholders with various interests will be valuable, especially with regard to strategic and interim goals for filling the EHS information gaps for nanomaterials. The NSET Subcommittee and NNI member agencies plan to make the priority-setting process a dynamic, open, and transparent process. Input from citizen and industry groups, academia, and other research entities will be gained through workshops, public hearings, and other means. Input will be carefully considered when establishing research priorities.

2. INSTRUMENTATION, METROLOGY, AND ANALYTICAL METHODS

This area identifies research to enable new instrumentation and standard measurement protocols, as well as the development of reference materials and data related to the detection, characterization, and measurement of physical, chemical, and biological properties of engineered nanoscale materials in environmental and biological matrices (e.g., air, water, soil, cells, tissues, organs, organ systems, and whole organisms). Also addressed is the development of terminology, nomenclature, and standards for engineered nanoscale materials, a cross-cutting need for each research area discussed in this document.

TERMINOLOGY, NOMENCLATURE, AND STANDARDS DEVELOPMENT FOR ENGINEERED NANOSCALE MATERIALS

Basic terminology and a comprehensive nomenclature or taxonomy for nanomaterials have not yet been developed, but development efforts are under way. Such terminology and nomenclature would enable nanomaterials, or products that contain nanomaterials, to be identified unambiguously across government(s), industry, and academia. Standardized language would thereby aid in effective communication among researchers and in the development of regulatory definitions applicable to nanomaterials. Also under way is standards development for instrumentation and metrology to characterize the properties of nanomaterials, as well as to measure and control exposures to nanomaterials. These standards will improve toxicology and scientific research, in general, as well as facilitate confidence in product consistency in commerce.

Selected Relevant Federal Government Actions

- Scientists from several Federal agencies as well as the NNI's National Nanotechnology Coordination Office (NNCO) are working on developing standards for nanotechnology, including terminology and nomenclature; measurement and characterization for nanomaterials; and environmental, health, and safety aspects of nanotechnology. NNI agencies are contributing to the work of U.S.-domiciled standards development organizations (including, for example, ASTM International, the Institute of Electrical and Electronics Engineers, and the National Electrical Manufacturer's Association) to develop voluntary, consensus-based nanotechnology standards for international use.
- In June 2004, the American National Standards Institute (ANSI) established a Nanotechnology Standards Panel to facilitate and coordinate United States efforts in nanotechnology standards development. Subsequently, the International Organization for Standardization (ISO) established a Technical Committee (ISO TC 229) for nanotechnologies and ANSI accredited a Technical Advisory Group (ANSI-TAG) to represent the United States on this ISO Technical Committee. One of the working groups of ISO TC 229 and its parallel in the ANSI-TAG are focused on developing terminology and nomenclature for nanotechnology.
- The United States leads the ISO TC 229 Working Group on Health, Safety, and Environmental Aspects of Nanotechnologies. At its June 2006 meeting, ISO TC 229 approved a U.S. submission of a new work item proposal to develop an ISO Technical Report on Current Safe Practices in Occupational Settings Relevant to Nanotechnologies, using the NIOSH document *Approaches to Safe Nanotechnology: An Information Exchange with NIOSH* as a benchmark.
- A second ISO TC 229 Working Group on Metrology and Characterization is developing standards for a minimum set of measurement methods for characterizing both single-wall and multiple-wall carbon nanotube materials for purity and types of contaminants—an important

2. Instrumentation, Metrology, and Analytical Methods

step both for improving consistency in conducting research on the potential toxicity of these engineered nanoscale materials and for advancing trade in these materials.

- ANSI is working with ASTM International, which under its E56 Committee on Nanotechnology has established a number of technical subcommittees: E56.01, Terminology and Nomenclature to develop and harmonize definitions of nanotechnology-related terms; E56.02, Characterization; E56.03, Environment, Health and Safety; E56.04, International Law & Intellectual Property; and E56.05, Liaison & International Cooperation. The first standard, E2456-06 Standard Terminology for Nanotechnology, was approved in July 2006. In addition, three standards on biological testing of engineered nanoscale materials and four standards on engineered nanoscale materials characterization and sample preparation are in draft status.
- ASTM International has formed a partnership to work jointly with IEEE, the American Society of Mechanical Engineers, Semiconductor Equipment Manufacturers International, American Institute of Chemical Engineers, and NSF International (formerly the National Sanitation Foundation) to develop global nanotechnology terminology standards. Several Federal agencies participate in one or more of these standards development organizations.

Research/Information Needs

Develop useful approaches to identify and categorize nanomaterials by size, composition, and morphology. General terminology is lacking for nanoscience and technology, including definitions and systematic terminology for material size, composition, and morphology.

Defining a common language for describing the unique phenomena and for sharing health and environmental effects research on nanomaterials is challenging. In order to understand research results and to compare those results to studies among similar materials, a minimum set of physicochemical characteristics of materials used in biological effects and fate/exposure studies and a common language for those materials must be developed.

Possible Research Approaches

Research that contributes to an internationally recognized system of terminology and nomenclature for nanomaterials will be most valuable.

A useful set of physicochemical characteristics may be modeled after the "minimum information about a microarray experiment" (MIAME) standards that evolved for microarray analysis (www.mged.org/Workgroups/MIAME/miame.html). Such targeting not only assists comparison of study results but also reduces inadvertent variation that contributes to confusion for extrapolations across studies.

Issues to consider in developing common language for nanomaterials EHS research include processes for data sharing, data provenance, analytical platforms, and ontologies. This latter category uses "object models" (i.e., relationships between words), to query and extract data, which allows users from disparate scientific fields to mine databases using their own disciplines' familiar keywords, rather than all parties agreeing on a common data dictionary.

ANALYTICAL TOOLS AND METHODS

Evaluating the effects of nanomaterials on the environment and human health may require considerable knowledge of the nature and properties of the nanomaterials, including such characteristics as purity, particle size and distribution, shape, crystal structure, composition, surface area, surface chemistry, surface charge, surface activity, and porosity. A broad array of analytical tools and methods are needed to perform such characterizations, including a wide variety of optical, microscopic, spectroscopic, chromatographic, and nuclear methods. In many cases further development of existing tools, or the creation of new instruments or approaches, will be necessary

2. Instrumentation, Metrology, and Analytical Methods

to obtain reliable and reproducible information for engineered nanoscale materials. Key to these tools and approaches is *metrology*, which is simply “the science of measurement.” This underlying information is critical in making the associations between specific nanomaterials, particular behavior, and resulting effects. Thus, research on instrument development is a cross-cutting need that affects many of the other research needs identified in this document.

Furthermore, there is currently a lack of generally accepted, acknowledged, and/or validated measurement methods, reference data, and standards for the determination of the nature and properties of engineered nanoscale materials. For example, representative reference species from broad classes of nanomaterials have not been established, yet these are necessary to develop metrology for measuring, testing, and characterizing materials in a wide range of biological and environmental media. Both the pure forms of the materials and the materials in altered states (such as in solution) require consideration. The relative lack of basic scientific information in this area poses significant challenges both for developing new materials and for regulatory review.

Selected Relevant Federal Government Actions

- The National Institute of Standards and Technology (NIST) supports this area through research to develop new analytical methods and measurement technology, development of methods to characterize and validate performance of conventional instrumentation, development of Standard Reference Materials, and operation of specialized nanotechnology facilities, including the new Center for Nanoscale Science and Technology, with access to a wide range of optical, mechanical, electrical, and magnetic measurement techniques for dimensional characterization and determination of material and mechanical properties at the macroscale, microscale, and nanoscale.
 - Topical areas at NIST include fundamental science and measurement techniques, characterization of materials, development of nanoscale electronics, nanochemistry, and nanobiotechnology methods, and quantum computing and communications. NIST-wide nanotechnology research also focuses on the miniaturization of analytical techniques for the detection or characterization of matter such as the development of cantilever and “lab-on-a-chip” devices for sensing, detection, and separation of matter traceable to the International System of Units (SI) units. (More information on these activities is available at www.cstl.nist.gov/nist839/839.04/microfluidics.html and www.ceramics.nist.gov/ftp/root/AR2005_Ceramics.pdf.)
 - Other NIST nanotechnology research activities include the development of micro-fabricated atomic frequency references and calibration services for force and torque at the nanonewton level. Funded metrology programs include Fundamental Metrology for Carbon Nanotube Science and Technology, Metrology for the Fate of Nanoparticles in Biosystems, and Bio-Imaging: A 21st Century Toolbox for Medical Technology.
 - Recent NIST workshops have included topics such as standardizing nanotube measurement, analysis, and reporting protocols for single-wall carbon nanotubes; measurement and standards needs in nanobiotechnology; and challenges associated with the characterization of particles (including those at the nanoscale) with sessions on sample preparation, statistical experimental design, and established and emerging measurement techniques.
 - In 2004 NIST opened a unique nanomaterial science research facility, the Advanced Measurement Laboratory (AML). The AML is designed to assist U.S. industry, university, and government partners with new high-accuracy measurement technologies, databases on the fundamental properties of nanomaterials, and other supporting tools and capabilities to promote advances in nanomaterial science.

2. Instrumentation, Metrology, and Analytical Methods

- In 2006, NIST established the Center for Nanoscale Science and Technology. The Center will contribute to progress in the NNI program component areas with emphasis on instrumentation research, metrology, and standards for furthering the development of tools and standards needed to advance research and to build the technical infrastructure for manufacturing and commercialization of nanoscale materials, structures, devices, and systems (see cnst.nist.gov).
- As part of the Center for Nanoscale Science and Technology, NIST established a nanofabrication facility that provides state-of-the-art ultraclean facilities for the fabrication of nanoscale devices, structures, Standard Reference Materials, microelectromechanical systems (MEMS), and bio-devices. It also provides access to a wide variety of measurement and characterization tools, technologies, and expertise to NIST and its partners.
- Products, standards, and technologies developed as part of these NIST-wide nanometrology research and development programs will support metrology needs for nanomaterials and related environmental health and safety efforts.
- Standard Reference Materials are being developed for the physical and chemical characterization of nanomaterials, including a suite of gold nanomaterials with diameters in the range 1 nm to 100 nm for calibration of instruments and measurements; physical *in vitro* and *in vivo* characterization studies in collaboration with the NCL; elemental Standard Reference Materials (thin films, single-phase nanoscale particles, and more complex systems) for electron and ion beam analytical imaging instruments; NIST Reference Material 8475 Carbon Nanotubes; and particle-size standards in the nanometer to micrometer size range for evaluating and calibrating specific types of particle size measuring instruments such as optical and scanning electron microscopes and light-scattering instruments.
- The Nanotechnology Characterization Laboratory (NCL) at the National Cancer Institute (NCI) conducts preclinical tests of the efficacy and toxicity of nanoscale particles intended for cancer therapeutics and diagnostics (see ncl.cancer.gov).
 - The NCL characterizes physical attributes of nanoscale particles, *in vitro* biological properties, and *in vivo* compatibility using animal models.
 - The NCL assists the bio-nanotechnology community in identifying relationships between the physical structure of nanomaterials and their biomedical activity relevant to nanomaterial safety and efficacy.
 - The activities within the NCL represent a formal scientific partnership of selected Federal agencies: the NCI with the U.S. Food and Drug Administration (FDA) and NIST.
 - The NCL has initiated a program for characterizing and cataloguing physical and biological properties of engineered nanomaterials used in cancer diagnosis and treatment.
 - The NCL is creating an informatics grid in which information will be made available relevant to the development of nanoscale drug delivery vehicles and structure activity relationships contributing to biocompatibility and toxicity (see nano.cancer.gov/about_alliance/nanotech_characterization_lab.asp).
- The Department of Energy (DOE) is establishing and operating five Nanoscale Science Research Centers (NSRCs) as user facilities (see nano.energy.gov).
 - Access to the NSRCs is open to all and based on merit review of submitted proposals, making comprehensive suites of state-of-the-art equipment and corresponding expertise broadly available to the scientific community.

2. Instrumentation, Metrology, and Analytical Methods

- The NSRCs are located close or adjacent to other major user facilities for X-ray, neutron, and electron scattering, and provide gateways to these powerful existing capabilities.
- The NSRCs also participate in the development of new tools for nanoscale characterization and analysis, including synchrotron beamlines with unprecedented spatial resolution for imaging, modular microlaboratories for facilitating measurements on nanomaterials and improving their comparability, and cantilever and "lab-on-a-chip" devices for sensing, detection, and separation.
- DOE efforts in the area of novel and improved analytical tools and methods for nanomaterials include the Transmission Electron Aberration-corrected Microscope (TEAM) project, a multiyear development effort to create the basic platform for the next generation of transmission electron microscopes:
 - Involving five electron scattering groups supported by DOE, as well as several commercial partners, the project re-envisioned the instrument from the ground up in order to maximize its capabilities, building on recent advances in compensating for electromagnetic lens imperfections. Thus, the instrument being developed will include an advanced and more stable column, an improved electron source, novel sample insertion and handling mechanisms, novel correctors for several levels of aberration both in the probe-forming and image-forming lenses, and other improvements to allow unprecedented resolution, tomographic imaging at the atomic scale, and additional flexibility for spectroscopic and other analyses. Further information on the TEAM Project is available at ncem.lbl.gov/team3.htm.
 - DOE is also supporting the development of other novel hardware and software for nanomaterial analysis, including instruments and detectors for neutron scattering research at the Spallation Neutron Source.
- NIOSH has developed a web-based Nanoparticle Information Library to help occupational health professionals, industrial users, worker groups, and researchers organize and share information on nanomaterials, including their health- and safety-associated properties (see www2a.cdc.gov/niosh-nil).
- The NSF supports R&D through universities, research laboratories, and small businesses to create new tools needed to advance nanotechnology research and commercialization, including next-generation instrumentation for characterization, measurement, synthesis, and design of materials, structures, devices, and systems. (More information is available at www.nsf.gov/nano.) Large experimental facilities have been funded through NSF's Major Research Instrumentation program. The largest contribution for new instrumentation is provided through single-investigator and small-group projects.
- NSF supports work on analytical tools and methods development through several user networks and university-based centers: the National Nanotechnology Infrastructure Network (NNIN), an integrated partnership of 13 user facilities, of which two are focused on characterization of nanoscale particles; a group of 16 Nanoscale Science and Engineering Centers, of which one is focused on novel instrumentation; a center on environmental aspects of nanomaterials; four centers on nanomanufacturing processes and tools; a network of six Materials Research Science and Engineering Centers; an Engineering Research Center focused on nanoscale measurements; and a Science and Technology Center focused on nanobiotechnology processes and tools. The NNIN network provides extensive support in nanoscale fabrication, synthesis, characterization, modeling, design, computation, and hands-on training in an open, hands-on environment available to all qualified users. NSF also

2. Instrumentation, Metrology, and Analytical Methods

supports analytical work through the Network for Computational Nanotechnology, whose mission is to connect theory, experiment, and computation in the field of nanotechnology.

- The Department of Defense (DOD), via the Defense University Research Instrumentation Program and other programs, provides DOD facilities and research to support the development of new instrumentation for nanoscience research.

Research/Information Needs

Develop methods for detecting nanomaterials in biological matrices, the environment, and the workplace. Analytical methods for identifying and measuring the critical parameters related to nanomaterials in biological systems, the environment, and the workplace are not well-developed or readily available. As a result, these important metrics are infrequently or inaccurately reported. Further development of these methods is critical to nanotechnology EHS research. Accurate and validated reference materials and/or protocols also are needed to define the limitations and specificities of each analytical method for the analysis of biological, environmental, and workplace samples (Roberts et al., 2006). Additionally, methods for detecting and measuring the effects of nanomaterials (i.e., absorbed and effective dose) in biological, environmental, and workplace samples are in their infancy and must be developed. (See Chapter 3, Nanomaterials and Human Health; Chapter 4, Nanomaterials and the Environment; and Chapter 5, Health and Environmental Surveillance.)

Understand heterogeneity in nanomaterials. The relationship of batch-to-batch variation in nanomaterial production and biological activity or toxicity is not understood at this time. This potential variation can affect the assessments of expected toxicity for materials in use. Purity assessments; particle size, shape, and structure analyses; and the determination of chemical composition of nanomaterials assist with understanding the heterogeneity in nanomaterials.

Understand the effect of modifications on the properties of nanomaterials. In the development of products, nanomaterials may undergo any number of modifications. These modifications may include coatings to reduce oxidation, addition of molecular groups to induce or diminish biological activity, or functionalizing them to enable their integration into final products. These modifications may affect the degradation of particles, their uptake by biological matrices, or the methods necessary to detect the presence of nanomaterials in human and environmental contexts.

Develop methods for assessing purity of materials. A variety of optical, microscopic, nuclear, chromatographic, and spectroscopic methods exist for assessing the purity of a material. Modifications or enhancements to these methods may be necessary, however, to apply them to nanomaterials. Validated measurement methods do not exist to assess purity of nanomaterials or to compare manufactured materials produced by different vendors or laboratories.

Develop methods for standardizing particle size and size distribution assessment. Rapid, statistically valid, standardized methods are lacking for measuring both the size and particle-size distributions of nanomaterials. Automated microscopic methods for the rapid analysis and screening of a large number of nanomaterials would greatly facilitate the acquisition of knowledge about properties of nanomaterials. Methods for determining the sizes of particles smaller than 5 nm are especially inadequate. It may be helpful to explore correlations of electron microscopy with other size-measurement techniques, such as differential light scattering, in an effort to provide new mechanisms for researchers to evaluate the quality and comparability of measurements of particle size and particle-size distributions in the nanoscale regime.

Develop methods and standardized tools for assessing nanomaterial shape, structure, and surface area. Determining shape, structure, and surface area with nanometer precision is a challenge using current methods and tools. In general, conventional electron microscopy is not fast enough to provide population statistics adequate to characterize the structure of nanoscale

engineered materials. A clear need is the capability for resolution on the atomic scale, and such capabilities are fundamental to primary calibration methods. A possible strategy for the determination of nanomaterial shape and structure is aberration-corrected analytical electron microscopy. Ion mobility mass spectrometry has not been thoroughly explored but may be an appropriate method for determining aggregation of nanomaterials. Surface areas may be determined using BET (Brunauer-Emmett-Teller) techniques, though this classical approach of using gas molecules as “rulers” likely needs to be modified for accurate characterization of nanoscale engineered materials.

Develop methods to characterize a nanomaterial’s spatio-chemical composition. At the nanoscale, where single defects and slight changes to surface dimension and composition can dramatically influence reactivity, proper characterization of spatial composition is critical. Most chemical analytical techniques are designed for bulk materials and lack the spatio-chemical resolution to resolve differences in composition at the nanoscale. Three-dimensional chemical characterization of nanomaterials at the 1 nm resolution level is necessary for accurate assessment of the chemical composition of nanomaterials. Applicable techniques may include secondary ion mass spectrometry, X-ray photoelectron spectroscopy, Auger electron spectroscopy, analytical electron microscopy, and X-ray microanalysis.

Develop an inventory of nanomaterials and their uses. National and international tracking and monitoring of the production and use of nanomaterials is limited, and current production levels of nanomaterials are not well known. In addition, there is little information on industry sectors and the size class of producers currently in production mode. Patterns and trends in production and use of products have not been comprehensively examined, and there is a paucity of data on trends (or projections) of growth. An inventory of materials and uses would assist in tracking and monitoring the production and use of nanomaterials. The value and cost of including in the inventory specific kinds of descriptive information and levels of detail should be considered.

The inventory could be used to examine patterns and trends in engineered nanomaterial production and use, including identification of industry sectors and specific establishments producing nanomaterials or products that contain nanomaterials, including particles.

Possible Research Approaches

A national program involving the Federal Government, industry, and academia could be established for characterization of nanomaterials. Such a broad-based program would help greatly with the analysis of nanomaterials in both pure and more complex forms, such as in solution or in biological or environmental matrices. The initial foci of such efforts could be evaluating purity assessments, size and distribution, shape, structure, spatial-chemical composition, and surface activity.

There is a lack of atomic- or molecular-scale modeling for nanomaterials. Coordination among analytical science and biological science practitioners will enable the modeling and possibly the prediction of biological interactions of nanomaterials. Collaboration or multidisciplinary approaches may speed the development of knowledge for proper sample handling and processing. Such approaches could provide fundamental insight into the physical and chemical properties of nanomaterials.

Other specific approaches for consideration include development of

- Standard Reference Materials for the chemical and physical characterization of nanomaterials
- global-scale, inter-laboratory, comparative exercises for the characterizing of nanoscale engineered materials at national metrological institute levels
- a program to accredit laboratories that characterize nanomaterials

2. Instrumentation, Metrology, and Analytical Methods

- nationally recognized standard protocols for sampling methods necessary to determine individual exposure to nanomaterials in the workplace (see also Chapter 5, Health and Environmental Surveillance)
- nationally recognized standard protocols for sampling methods necessary to determine biomarkers indicative of biological exposure to nanomaterials (see also Chapter 5, Health and Environmental Surveillance)
- nationally recognized standard protocols for determining the concentration of nanomaterials in environmental media such as air, water, soil, food, and biota (see also Chapter 3, Nanomaterials and Human Health)
- a database and mathematical modeling structure that synthesize environmental and biological response characteristics of nanomaterials in order to estimate the biological or environmental effects of changing a defined set of physical properties of a nanomaterial (see also Chapter 4, Nanomaterials and the Environment)

3. NANOMATERIALS AND HUMAN HEALTH

This area addresses research on the biological response to engineered nanoscale materials and their byproducts, the results of which may contribute to identifying potential adverse health effects in humans. This includes research on subcellular components, cells, tissues, organs, organ systems, and whole organisms to determine biocompatibility and toxicity of various engineered nanoscale materials; and research to evaluate current toxicity screening tests and develop new tests as needed.

Size, shape, and surface chemistry are among key properties central to the utility of nanomaterials. These properties also fundamentally influence the way these materials interact within the human body. Understanding how the various characteristics of nanomaterials affect their biocompatibility and toxicity will support development of safer nanomaterials and nanotechnology products. Development of well-integrated, multidisciplinary research teams is critical to enable these studies.

One example of the roles nanomaterial properties play is how changes to surface chemistry can affect the biocompatibility and toxicity of particular nanomaterials. Positively charged nanoscale lipid vesicles (nanovesicles) induce cerebral edema, but neutral and low concentrations of negatively charged nanovesicles do not (Lockman et al., 2004). Studies have shown that modifying the surface of nanomaterials with surfactants or biocompatible polymers (e.g., polyethylene glycol) reduces the toxicity *in vitro* (Derfus et al., 2004) and alters the half-life and tissue deposition *in vivo* (Ballou et al., 2004). Such findings are relevant to drug delivery, for understanding the potential distribution of nanomaterials in the body, and for evaluating biocompatibility and toxicity. However, these findings are material-specific and are difficult, at present, to extend to broad categories/classes of materials.

Nanoscale materials similarly may vary in their ability to be introduced into and circulated through the body. For example, one study discovered ultrafine carbon transport from the olfactory mucosa in nasal passages, via the olfactory nerve, to the olfactory bulb inside the blood-brain barrier (Oberdörster et al., 2004). Other studies have demonstrated that semiconducting quantum dots translocate to local lymph nodes in animals following intradermal or footpad injections (Kim et al., 2003; Roberts et al., 2005) or following topical application to dermabraded skin (Gopee et al., 2006).

Seemingly more so than at larger scales, the shapes of nanomaterials have interesting implications for biocompatibility. Current manufacturing technologies with atom-by-atom assembly of nanomaterials under highly controlled conditions allow synthesis of materials having the same chemical composition but different shapes. Studies of zinc oxide (ZnO) nanomaterials suggest that changes in shape alone (e.g., particles, cages, and “belts”) influence physicochemical properties (Wang et al., 2004), which in turn can influence biological activity.

BIOLOGICAL RESPONSE

Homeostasis describes the totality of the physiological pathways and mechanisms that keep the body within the functional parameters defined as good health. Environmental exposures shift those parameters. The body’s ability to minimize the impact of an exposure and maintain homeostasis distinguishes biocompatibility from toxicity. Sentinel mechanisms designed to maintain homeostasis include the antioxidant pathways, inflammation, and immunity. The magnitude of the protective response is generally proportional to the magnitude, complexity, and duration of the exposure. But elevated biological response or persistence of the exposure could lead to tissue injury and chronic adverse health effects.

3. Nanomaterials and Human Health

Physiological response to nanomaterials is complex and influenced by physicochemical properties such as size and composition; purity of material following synthesis; type and degree of surface modifications; the inclusion of a surfactant or vehicle; the binding of biological molecules to the material following exposure; and the types of cells and organs exposed and degradation characteristics. Moreover, route of exposure as well as genetic, life status, and susceptibility factors may affect physiological response. Status factors include age, sex, or socioeconomic status that may influence susceptibility to an exposure. In short, nanomaterials research, although in its infancy, has begun to provide clues about nanomaterial interaction with human physiology. Extensive existing scientific literature on ultrafine and fine particles and fibers has contributed greatly to understanding the physical and biological properties of these materials and provides a scientific basis for developing hypotheses for testing engineered nanomaterials.

The need for specific studies on the biological response to nanomaterials highlights another research challenge: the limited availability of well-characterized materials in sufficient quantity. Consequently, most current research is performed *in vitro*, not *in vivo*, and assesses acute exposure, not chronic exposure. Novel biological response, when identified, may necessitate development of new test methods to evaluate novel behavior of nanomaterials *in vivo*, and new *in vitro* tests to predict novel *in vivo* behavior. Moreover, although results have shown the utility of studies *in vitro* to compare relative toxicities of specific nanomaterials (Hussain et al., 2005), standardized dosing protocols have yet to be established for the testing of such materials *in vitro*.

Additionally, modifications to the surfaces of nanomaterials can alter biochemical reactivity and should be reflected in calculations of absorbed and effective dose. Processes that may modify nanomaterial surfaces include intentional or inadvertent chemical changes that may occur through sonication, grinding, or suspension in a vehicle in preparation for administration to a subject. Coatings may be applied before administration or may spontaneously develop during and after administration. Any surface modification has the potential to strongly influence the material's reactivity. Physicochemical characterization of nanomaterials following preparation and administration is required to understand the dose-response behavior of nanomaterials in biological systems.

Selected Relevant Federal Government Actions

- NIH's NCI has initiated a program at the Nanotechnology Characterization Laboratory for characterizing and cataloguing physical and biological properties of nanomaterials used in cancer diagnosis and treatment (see ncl.cancer.gov/). The program is working to standardize approaches to characterize nanomaterials through physical, *in vitro*, and *in vivo* assays. The NCL, a partnership of NCI with NIST and FDA, will track and measure health effects related to nanotechnology, including EHS. NCL is developing standard protocols for physical characterization, *in vitro* mechanisms of toxicity, and identifying parenteral ADME/Tox profiles (Absorption, Distribution, Metabolism, Elimination and toxicology) of nanomaterials intended for medical applications. This knowledge can serve to inform environmental toxicologists about toxic mechanisms, target organs, and systemic clearance mechanisms for nanomaterials. Data resulting from NCL assays will help inform the nanotechnology community as it makes assessments of the overall risks involved in the manufacture, use, and disposal of nanomaterials
- The National Institute of Environmental Health Sciences (NIEHS) has developed a trans-NIH and interagency Funding Opportunity Announcement to support research to investigate the biocompatibility and toxicity of industrial nanomaterials in mammalian systems. Six NIH institutes are partnering with the National Institute for Occupational Safety and Health, and the Environmental Protection Agency.

3. Nanomaterials and Human Health

- The National Toxicology Program (NTP), a partnership among NIEHS/NIH, NIOSH/CDC, and FDA, has developed a Nanotechnology Safety Initiative (ntp.niehs.nih.gov/go/nanotech) that is focusing on three areas of research with respect to specific groups of nanoscale materials. Results from these NTP studies are anticipated to be available in the next 1–5 years, depending on the type of study. Results from longer-term rodent studies will also likely take several years. The three areas are
 1. non-medical, commercially relevant and available nanoscale materials to which humans are being exposed, e.g., cosmetics
 2. representative nanoscale materials from specific classes (e.g., fullerenes and metal oxides) so that information can be extrapolated to other members of those classes
 3. subsets of nanoscale materials to test specific hypotheses about key physicochemical parameters (e.g., size, composition, shape, or surface chemistry) that might be related to biological activity.

For all three of these areas, research activities are focusing initially on four classes of nanoscale materials:

1. metal oxides (e.g., TiO_2 and ZnO), in collaboration with the Food and Drug Administration's National Center for Toxicological Research (NCTR)
 2. fluorescent crystalline semiconductors (quantum dots, in collaboration with NCTR)
 3. fullerenes (in collaboration with NIEHS)
 4. carbon nanotubes (in collaboration with NIOSH)
- NIOSH has established the Nanotechnology Research Center, which provides national and world leadership for research into the implications of nanoscale materials for work-related injury and illness. As part of its nanoscale material research program, NIOSH conducts toxicology studies of selected occupationally relevant nanomaterials (carbon nanotubes and metal oxides) for pulmonary, cardiovascular, and dermal effects.
 - In 2003 EPA began to support research to address health, ecological, and environmental implications of nanotechnology through its Science to Achieve Results (STAR) grants program. In 2005 and 2006, EPA's STAR program partnered with NIOSH, NSF, and NIEHS in funding grants to examine the health and ecological effects of various classes of nanomaterials such as carbon-based, metal-based, and dendrimers. These grants examine a range of toxic endpoints of nanomaterials in the body (cellular cytotoxicity; gastrointestinal toxicity, pulmonary toxicity; genotoxicity) and ecotoxicity (terrestrial and aquatic) for various classes of nanomaterials (see es.epa.gov/ncer/nano/research/index.html). EPA's Nanotechnology White Paper (U.S. EPA, 2005) identifies research needs that will lead to a strategy to complement, enhance, and integrate EPA's intramural and extramural health and ecological effects research to meet its mission and needs in the areas of environmental, health, and ecological implications of nanomaterials, such as comprehensive *in vivo* toxicity assessments of nanomaterials before and after interactions with environmental media associated with their applications; validated toxicity test methods; hazard identification; identification of susceptibility factors; mechanism(s) of injury and mode(s) of action; and development of models to predict nanomaterial toxicity.
 - The Department of Defense supports research to enable physicochemical characterization of nanomaterials and associated toxicology assessments in marine, aeronautical, terrestrial, and space environments. This research includes developing approaches to assess, avoid, and abate adverse health (or environmental) impacts from defense utilization of nanomaterials.
 - The National Science Foundation supports fundamental research (except for clinical testing) on EHS implications of nanotechnology. NSF-funded basic research related to nanomaterials and

3. Nanomaterials and Human Health

human health involves all the NSF research directorates and addresses natural, incidental, and manufactured nanoparticles and nanostructured materials in the air, water, soil, biosystems, and working environments. Four NSF Nanoscale Science and Engineering Centers are investigating the safety of manufacturing nanoparticles: (1) Rice University (evolution of manufacturing nanoparticles in the wet environment); (2) Northeastern University (occupational safety during nanomanufacturing); (3) University of Pennsylvania (interaction between nanomaterials and cells); and (4) University of Wisconsin, Madison (EHS effects of nanostructured polymers). NSF's National Nanotechnology Infrastructure Network includes centers at two of its 13 major nodes (University of Minnesota and Arizona State University) with a focus on nanoparticle characterization.

- NSF has also funded about twenty interdisciplinary research teams (NIRTs) in areas related to basic understanding of nanomaterials and human health. Three examples are shown below:
 1. "Reverse Engineering Cellular Pathways from Human Cells Exposed to Nanomaterials" (0436366, Mary Jane Cunningham, Medical Center Houston). This research is now yielding results suggesting that single wall nanotubes are relatively nontoxic (comparable to silica) to primary human cells (skin, lung).
 2. "Biocompatible Nanoparticles for Probing Living Cellular Functions and Their Potential Environmental Impacts" (interdisciplinary team award 0507036, Nancy Xu et al., Old Dominion University). In this project a team of biologists, engineers, and chemists are designing biocompatible nanoparticles for sensing and measuring in real time transport mechanisms in cell membranes. The study will lead to new knowledge on transport of nanoparticles through protein membranes and on design and assembly of molecular pumps and sensors.
 3. "Understanding Robust Large Scale Manufacturing of Nanoparticles and Their Toxicology" (interdisciplinary team award 0506968, Mitchell Smooke et al., Yale University). The project involves partnership between academia, government, and industry, as well as the disciplines of chemistry, chemical and mechanical engineering, and medicine. The study is employing a specialized reactor to generate engineered nanoparticles in collaboration with Cabot Corporation, the world's largest manufacturer of nanoparticles. Extensive toxicology tests will be performed. Mechanisms of particle-cell interactions will be evaluated and potential adverse/beneficial effects will be determined.
- Federal agencies support meetings, symposia, and conferences, such as the 2005 Frontiers in Aerosol Dosimetry Conference, the 2005 Materials Science Conference, and the NanoTox 2006 Conference as forums for nanoscience collaboration and dialogue.

Research/Information Needs

Understand the mechanisms of interaction between nanomaterials and the body at the molecular, cellular, and tissue levels. Cell culture systems and animal models indicate that some nanomaterials activate oxidative stress, inflammation, and immunogenic responses. Those reactions can lead to acute and chronic pathologies. However, studies of these systems and models are considered valid only for singular materials tested and at the specific doses tested. They may not identify the mechanism of action relevant to exposures or doses that might occur from use of other nanomaterials.

Understand the absorption and transport of nanomaterials throughout the body. A thorough understanding of nanomaterial physicochemical properties and their interaction with the body's molecular and cellular processes is essential to development of biocompatible nanomaterials. Although the translocation of nanomaterials through normally protective barriers in the body may pose a hazard for certain environmental exposures, it may actually be beneficial for specific

medical applications. For example, some studies link translocation of pulmonary nanomaterials into the circulatory system with cardiac and blood clotting effects. On the other hand, modifying the surfaces of nanomaterials may target them to specific locations in the body or actually promote or prevent their translocation throughout the body. Included should be epidemiological research on the development of atherosclerosis and vascular and blood biocompatibility. There is also a need for understanding the potential for accumulation of nanomaterials in organs and tissues of food-producing animals. To complete the ADME profile, it is important to identify the mechanisms of metabolism (especially breakdown of complex nanomaterials that contain multiple active moieties) and the routes of excretion.

Understand the long-term effects of implantable nanomaterials and other means of continuous exposure. Several nanomaterials have promise as scaffolding in bone repair and nerve regeneration and in replacement of degenerated knees and hips. Noninvasive techniques for monitoring the performance of these devices over their expected extended service (lifetime) are needed. Many of these devices will be subject to wear and degradation. The toxicity and clearance pathways of wear debris and degradation products need to be understood, and clinical indicators of adverse host response to the degradation products need to be identified.

Identify or develop appropriate *in vitro* and *in vivo* assays/models to predict *in vivo* human responses to nanomaterials exposure. Established *in vitro* and *in vivo* assays are available to measure the production of oxidative, chemical species, DNA damage, genetic toxicity, inflammation, and immune function. These assays provide information on the most common biological responses to an exposure. Given the novel physicochemical properties of nanomaterials, however, the ability of *in vitro* systems to predict *in vivo* response needs to be monitored. It should also be noted that animal models do not always predict human biocompatibility and toxicity. Newer biotechnologies (e.g., genomics, proteomics, and metabolomics) provide research tools that may detect novel biological responses to nanomaterials and may suggest new and more effective types of assays. Standards for handling of nanomaterials for *in vitro* and *in vivo* testing are required, e.g., appropriate solvents and dosing formulations, methods to prevent agglomeration, stability conditions, etc. This will improve the reliability, reproducibility, and accuracy of the assays and methods used within a laboratory and among laboratories.

Integrate biological data on nanomaterials into predictive physiology-based, pharmacokinetic (PBPK) models of toxicity. A PBPK model is a mathematical description of the relationship between the physicochemical properties of a material and the physiological and pharmacokinetic responses in anatomically distinct regions, or “compartments,” of the body over time. Validated PBPK models with good predictive power may be used in risk assessment to identify potential target organs, predict disposition of a new material, and set research priorities.

Understand generalizable characteristics of nanomaterials in relation to toxicity. Initial research suggests that some properties—surface area, charge, specific surface modifications—may have general relevance to understanding nanomaterial toxicity. There is a need to collect and extend this information, perhaps along with structure-activity relationship modeling (SAR), to support decision making regarding new nanomaterials. SARs increasingly are being used for the analysis of chemicals to identify molecular features/attributes of concern that influence the biological activity of a given molecule.

Develop integrative databases of engineered nanomaterial properties and effects. Information regarding the physical properties, fate, and effects (biological and environmental) of nanomaterials is available through research and in the course of commercial development of nanomaterials. There is potentially great value in collecting and integrating these data in ways that extend scientific understanding beyond that gained in individual experiments. However, the range of properties

across material chemistries, shapes, and sizes is potentially so vast that synthesis of information within individual research efforts presents a daunting task.

It therefore would be worthwhile to consider development and maintenance of an integrative database that could combine and relate data across experiments in an open framework. Research is needed specifically to define a process for capturing data from disparate sources, to explore relationships of data types with respect to properties and biological or environmental effects; to synthesize information in ways that support risk management decision making; and to establish management approaches for updating and maintaining these databases. While it is unlikely that the NNI agencies can independently complete the research required to develop such capability—which is needed in nearly every field of scientific and commercial endeavor—it is important that these needs not be overlooked.

Determine the applicability and adequacy of existing occupational and environmental particle/particulate health effects databases to predict or assess the biological and health effects of engineered nanomaterials. One major research issue relates to the utility or adequacy of health effects and toxicological information derived from published literature and reports on occupational and environmental health effects. A particular question relates to the utility of existing data from air-particulate-matter research for a variety of natural and manmade processes. Arguments for use of this information include the potential for substantial insight from existing epidemiologic and mechanistic research. Arguments against this approach include the confounding effects of impurities and the lack of uniformity in particle size.

Possible Research Approaches

Understanding the characteristics of biocompatibility and toxicity may require some new tools, methods, and metrics. Development of tools—especially nondestructive methods—that measure particle size and quantity within cells and tissues will be critical to the success of bioeffects research. Such tools are essential for exploring the relationships between environmental exposure, absorbed dose, and effective dose.

Multidisciplinary research teams that combine expertise in physical and biological sciences will be critical for understanding the relationships between nanomaterial physical characteristics and the exposure, uptake, and biology at the systemic, organ, cellular, and molecular level. One major goal of a multidisciplinary approach is elucidating important determinants of biocompatibility and toxicity that require measurement, so as to enable these determinants to be applied across classes of nanomaterials. Such multidisciplinary studies would also inform appropriate measures for exposure and benefit/risk analysis and assessment, and risk management. Nanotechnology initiatives under way at several NNI agencies, including EPA, NSF, NIH, and within NIH, the NCI's Alliance for Nanotechnology in Cancer, are model multidisciplinary programs of this kind.

EXPOSURE: ROUTES AND MEASUREMENT

Dose in a biological system is difficult to measure directly, so exposure is commonly used as a surrogate, and it is frequently measured at the border between the environment and the biological system as a mass concentration (e.g., milligrams per cubic meter of air). The exposure-response relationship is a key to understanding the safety of nanomaterials. Determining the doses, or quantities, of a material that will cause physiological responses in humans resulting from exposure requires the knowledge of the physicochemical properties of the material, the exposure conditions, the deposition and clearance, and the susceptibility of the system or person to the exposure. The type and magnitude of a biological response to a nanomaterial indicate the biocompatibility or toxicity of the nanomaterial.

Selected Relevant Federal Government Actions

EPA's 2003, 2005, and 2006 STAR grants and current intramural research efforts are examining the detection, dosimetry, and fate of nanomaterials in complex biological systems following dermal, oral, and inhalation exposures as well as cellular interactions and uptake. For example, pulmonary and gastrointestinal toxicity studies involve the determination of the potential fate of nanomaterials that enter the body via inhalation or ingestion, respectively, and their translocation throughout the body (es.epa.gov/ncer/nano/research/index.html). EPA's Nanotechnology White Paper (U.S. EPA, 2005) identifies research needs that will lead to a strategy to complement, enhance, and integrate EPA's intramural and extramural efforts to address research needs associated with nanomaterial detection, dosimetry, and fate in biological systems.

EXPOSURE ROUTES

Assessing exposure to nanomaterials requires understanding relevant routes of exposure. For a material (nanoscale or otherwise) to induce a measurable biological response, it must enter the body, usually through the respiratory tract, skin, eyes, or digestive tract, or through intravenous exposure of patients and healthy donors, and reach an appropriate site in the body at sufficient concentration and for a necessary length of time. The relationship of exposure to uptake differs for each route of exposure and is a function of the physicochemical characteristics of the material and the structure and function of the organ or system that acts as the entry point.

The respiratory tract. The upper airways of the lung have a relatively robust protective cellular layer (epithelium), but the alveoli (the regions of the lungs where gas exchange occurs) are deeper and more vulnerable. Research has shown that nanomaterials smaller than 100 nm (that is, those not in large agglomerates) deposit at higher concentrations in the alveoli, whereas agglomerated nanomaterials with diameters larger than 100 nm deposit at higher concentrations in the upper airway. Research has also demonstrated that nanoscale particles can be taken up by sensory nerve endings within the airway epithelia, followed by axonal translocation to ganglionic and central nervous system structures. For example, as noted earlier, animal studies have shown that inhaled or intranasally instilled nanoscale particles can be transported via the olfactory nerve to the olfactory bulb (Oberdörster et al., 2004; International Commission of Radiologic Protection, 2003).

The skin. The skin has a strong external barrier, the stratum corneum, which protects sensitive internal organs from environmental exposures. Although healthy skin is generally considered impervious to particle exposures, some studies suggest that nanoscale materials penetrate hair follicles and sebaceous glands, or move through the lipid pathway located between the cells of the stratum corneum (Bennat, Müller-Goymann, 2000). The relationship of the dose of nanomaterial to which the skin is exposed and the dose absorbed into the skin is not well understood. Furthermore, there is conflicting evidence regarding the ability of particulates to penetrate through the stratum corneum. Several unpublished studies suggest that nanoscale titanium dioxide does not penetrate the skin (RS/RAEng, 2004), whereas other recent reports demonstrate that nanoscale particles can enter the epidermis and dermis through intact stratum corneum (Ryman-Rasmussen et al., 2006) and through compromised stratum corneum, resulting in translocation of materials to the lymph nodes and liver (Gopee et al., 2006).

The digestive tract. Particle uptake in the digestive tract has been well studied, mostly for drug delivery. This complex system absorbs macromolecules at numerous points along its length. Several studies demonstrate uptake of nanomaterials, including organ-specific targeted uptake that utilizes surface modification as the targeting methodology. Nanomaterials also can be ingested when they are transferred from hand to mouth, and ingestion accompanies inhalation exposure when particles are cleared from the respiratory tract via the mucociliary escalator (International Commission of Radiologic Protection, 2003).

3. Nanomaterials and Human Health

Injection or Implantation. Particles may be injected into a patient via the subcutaneous, intramuscular, or intravenous routes, or may be injected directly into a tissue, organ, or tumor. These may be intended to target specific organs, tumors, and diseases or may serve as imaging and diagnostic agents. The disposition and biocompatibility of the particles will depend on ADME/TOX profiles—which are known to be tightly linked to particle size and surface chemistry. Particles may also be released from implanted devices, whether as a result of designed resorption, or as a result of matrix material wear and degradation. These may accumulate in local tissues, or be transported to filter organs, or may be excreted.

Research/Information Needs

Understand the relationship between the properties of nanomaterials and how they affect uptake via lungs, skin, and digestive tract. The relationships between the absorption of nanomaterials into the body and the nanomaterials' properties such as size, surface chemistry, and agglomeration characteristics are largely unknown. For example, research has just begun to explore the uptake of nanomaterials by the olfactory mucosa and the effects of particle size and surface charge on absorption of nanoscale particles into and through skin. Intravenous exposure is an additional example of research needed in this area. Valid biomarkers of exposure and response, particularly if exposure is route-specific, would support this goal. Successful completion of such research will improve exposure assessment methods.

Assess body burden. The total quantity of material in a biological system at any given time is a function of absorption and excretion of the material; it is defined as the body burden. Traditionally, body burden is determined by elemental analysis, a quantitative technique requiring destruction of the biological material. Body burden is expressed as mass of the material per gram of body mass. However, for nanomaterials this traditional technique may not be a useful metric for assessing biological effects. The definition of body burden may need revision because of uncertainty surrounding the correct dose metric for nanomaterials—instead requiring a new definition that reflects novel properties, surface area, and chemistry. That applies both to measurement of body burden for *in vivo* studies and to cellular uptake studies *in vitro*. Few tools exist to analyze the nanomaterial particle number and size distribution in cells or tissues.

Understand the relationship between the matrix (the material within which the nanomaterial is used or delivered) and absorbed dose, including synthesis byproducts and other impurities. The forms and matrices within which nanomaterials will exist are likely to be as diverse as their applications. The byproducts of synthesis and application, such as metals, could affect biological response, or for skin preparations, an active ingredient or contaminant could alter uptake and transport of nanomaterials via emulsions, capsules, or other nanoscale delivery devices designed to penetrate the skin barrier.

EXPOSURE MEASUREMENT

Although exposure measurements are typically based on mass, current research indicates that for at least some nanomaterials, mass may be less important than particle size, surface area, and surface chemistry (or activity) (Magrez et al., 2006). It is also likely that some classes of engineered nanoscale materials could have different, possibly unique, primary determinants of dose relative to toxicity. Accurate and useful measurement techniques are also important because agglomerated nanomaterials may either retain or lose their emergent properties—or take on new properties—thus affecting the potential biological response.

Research is ongoing to explore the relative importance of other exposure metrics and methods. This includes developing techniques for characterizing aerosols and particles in-line (i.e., during production/manufacture) or as products (such as methods for measuring the surface areas of

nanometer-diameter aerosols and particles) and to quantify their composition and structure. Some challenges have arisen in attempts to measure exposure and dose of nanomaterials, including

Mass metrics. When considering mass as exposure and dose metrics, a critical question is whether it is most appropriate to measure the mass of individual particles (which are less than 100 nm in one dimension) or massed agglomerates (which may be larger than individual particles). The dynamics of nanomaterial agglomeration can play a critical role in determining the pulmonary deposition of respirable nanoscale material, where larger aggregates of particles tend to deposit within the airways, while dispersed nanomaterials often reach the alveoli.

Particle number metrics. The importance of particle number concentration as exposure and dose metrics is not clear from existing toxicity data. In many cases, biological response may relate more to total particle surface area than with sheer number of particles. However, in some cases the number of particles depositing in the respiratory system or penetrating beyond the respiratory system may be important.

Surface area and chemistry metrics. Any material's biochemical reactivity is highly dependent upon its surface chemistry. Bioreactivity may be more pronounced in nanoscale particles, where, for a given number or mass of particles, the total surface area delivered is dramatically larger than for the equivalent number or mass of microscale particles. Studies in rodents have shown that the toxicity of some nanoscale particles correlates with increased particle surface area (Oberdörster et al., 1992, 2000; Tran et al., 2000), whereas other studies demonstrate no increase in toxicity with decreased size (Warheit, 2006).

Research/Information Needs

Develop methods to quantify and characterize exposure to nanomaterials. Nanomaterials differ in significant ways from traditional materials for which established measurement procedures and equipment exist. One factor involves instrumentation: in general, many available devices and methods cannot accommodate and analyze samples at the nanoscale. Another factor involves uncertainties regarding the appropriate parameters for sampling and analysis. Procedures for measuring traditional materials are based on particle mass and bulk chemistry as characteristics that most determine whether the material is likely to have adverse effects. For certain nanomaterials, current research suggests that mass and bulk chemistry may be less important than particle size, surface area, and surface chemistry (or activity) as the most relevant parameters for measurements. Potential methods and technologies for measuring exposures to airborne nanomaterials, such as instruments that measure particle number and surface area, need to be evaluated.

Develop methods to quantify and characterize nanomaterials in biological matrices. Biological matrices (both internal to the body and external) are complex optical, physical, and chemical environments that may change the surface chemistry of administered nanomaterials. For example, lung surfactant proteins may either be applied to nanomaterials post-synthesis to prevent agglomeration, or they may adhere to nanomaterials in a random manner after the nanomaterials have made contact with fluids and tissues in the airways and lungs. Although many technologies can detect the presence of nanomaterials in tissues, technologies that can measure particle size, surface area, and biochemical status within an organism are not readily available. Analytical methods, particularly those that would enable the integration of exposure across exposure routes (e.g., those for biomarkers that would be indicative of inhalation, ocular, and dermal exposures), need to be explored and validated for quantification and characterization of nanomaterials in biological and other complex matrices. (See also Chapter 2, Instrumentation, Metrology, and Analytical Methods).

4. NANOMATERIALS AND THE ENVIRONMENT

This area describes research aimed at identifying, understanding, and controlling the potential effects of engineered nanoscale materials on both relevant ecological receptors and the ecosystems that they occupy, and research on fate and transport of engineered nanoscale materials that leads to a better understanding of the mechanisms by which nanoscale materials enter, remain, degrade, and are transported through environmental media.

ENVIRONMENTAL HAZARD CHARACTERIZATION

Although much of the current research into nanomaterial hazards has focused on human health, the models employed in these studies also offer insight into hazards for the broader range of environmental biota. Ongoing toxicity studies at EPA, NIOSH, and the National Toxicology Program, for example, will produce useful information to help elucidate environmental hazards of nanomaterials. However, the complexity of environmental hazards extends beyond basic mammalian toxicology. Physiological differences among various aquatic and terrestrial animal classes will lead to unique considerations; for example, the gills of aquatic organisms and avian respiratory systems pose issues not addressed by studies on mammalian respiratory systems. Terrestrial and aquatic plant physiology differ even more from mammalian systems. Currently, very few nanomaterial toxicity or uptake/distribution studies have been conducted with aquatic or terrestrial species, and no chronic, full, or multigenerational life cycle studies appear in the literature.

ENVIRONMENTAL TRANSPORT AND FATE

Environmental exposure to nanomaterials may occur via air, water, or soil. While little is known about the airborne transport specifically of nanomaterials, substantial research has explored the dispersion of incidental ultrafine particles arising from such sources as exhaust plumes. Particulates whose sizes range between 1 and 100 nm will move as governed principally by diffusion, whereas the movement of larger particles will be more influenced by inertial and gravitational forces (in the absence of buoyancy forces such as turbulence).

Engineered nanoscale materials released to the atmosphere will diffuse from areas of higher to areas of lower concentrations. Nanomaterials mix and disperse rapidly, and their transport and concentration can be influenced by air movement. Nanomaterials often agglomerate into larger masses, depending on the number of particles and their mobility. Since both of these parameters tend to increase with decreasing size for a given mass concentration, agglomeration tends to increase rapidly at very small size ranges. The result of such agglomeration, however, may still be a nanoscale particle. For nanoscale particles, other factors such as surface charge and humidity may influence particle agglomeration and settling. Some types of nanomaterials could become attached to dust, pollen, or other airborne particulates.

Particles larger than 1 μm tend to deposit on surfaces mainly through inertial impaction and sedimentation. However, for nanoscale particles, the main mechanisms leading to deposition will include diffusion and electrostatic forces.

Wastewater streams and runoff from areas around a manufacturing plant—or around a waste dump or another place where nanoparticles are used, discarded, or released—might transport nanomaterials into the environment. Solubility and stability largely determine how a material disperses in water. Researchers have shown that C_{60} fullerenes, which are considered virtually insoluble in water, form colloids that remain suspended in water (Andrievsky et al., 1999, 2002).

Thus, even though particular nanomaterials are insoluble in water, their agglomerates may persist in solutions.

Complexation and diffusion affect how a material penetrates into soil. Researchers at Rice University have developed laboratory models that simulate freshwater aquifers using spherical silicate glass beads to investigate how eight different types of nanoscale carbon-based and oxide particles migrate through porous media. These researchers have found that the transport behaviors of these materials differ widely. Fullerol particles (hydroxylated C_{60}) displayed the highest mobility, whereas agglomerate C_{60} fullerene particles were among the least mobile under the specific conditions of the model aquifer system (Lecoanet, Bottero & Wiesner, 2004).

Nanoscale products might be intentionally released into surface and groundwater systems and aquifers or soil for beneficial purposes, such as cleanup of toxic spills. Light-activated nanoscale titanium dioxide particles are being investigated for removing organic compounds from various media. One field study examined the efficacy of bimetallic nanoscale particles to remediate groundwater contaminated with aliphatic chlorinated hydrocarbons (Elliot & Zhang, 2001).

Any complete knowledge about the environmental fate of nanomaterials must account for a host of factors including bioavailability, bioaccumulation, persistence, synergistic effects of nanomaterials with other contaminants or naturally occurring compounds, formation of toxic metabolites, mobility of the material from one media to another, water solubility and groundwater contamination, transformation of compounds, and ultimate fate in ecosystems.

Engineered nanoscale materials have shown sensitivity to their physicochemical environment. For example, small changes in the surface charge of nanoscale silicon wires produce dramatic changes in electrical conductance (Cui et al., 2001). Similarly, small pH changes can dramatically affect solubility, which may enhance or diminish agglomeration. The effect of such small transformations on nanomaterial reactivity, transport, or fate is not well understood. To date, most investigators have explored the effects of nanomaterials in natural environments such as forests or wetlands. Programs are also needed to explore the influences of aging or degrading nanomaterials in reactive environments such as waste treatment plants that employ incineration or chemical treatment. Changes in nanomaterials through these processes may result in new or unexpected exposures, or affect fate and transport in indoor or outdoor environments.

Selected Relevant Federal Government Actions

- EPA is funding research on environmental exposures and effects, including plants, microbial species, and other organisms in the natural environment. Studies are under way at the University of Florida and Arizona State University on aquatic ecosystems; at Purdue University, the University of Delaware, and Rice University on microbial populations; at the universities of South Carolina and California, Berkeley, on estuarine systems; and at the Georgia Institute of Technology and Rice University on soil systems.
- EPA is funding research at universities to examine the fate of nanomaterials such as quantum dots, carbon nanotubes and nanowires, and metal oxides in the natural environment.
- EPA and NIOSH are funding work on the dispersion of nanoscale particulate aerosols.
- EPA, through its STAR grants program, began funding research in environmental toxicity, fate, and transport in 2004. To date the agency has funded 15 projects in fate, transport, and exposure assessment, and five projects addressing environmental toxicity. Descriptions of these projects are available at www.epa.gov/ncer/nano.
- As discussed in Chapter 3, several of the NSF-funded Nanoscale Science Engineering Centers include research on issues related to health and environmental implications of nanotechnology. In particular, the Center for Biological and Environmental Nanotechnology at Rice University is looking at the interface between nanoparticles and biological systems and is studying various

4. Nanomaterials and the Environment

environmental effects resulting from exposure to nanomaterials. NSF's network of nanotechnology user facilities, the National Nanotechnology Infrastructure Network (NNIN) and the Network for Computational Nanotechnology (NCN), are available for use by all researchers in academia, industry, and government who need specialized tools for nanomaterials characterization, for example, in the course of their work to investigate the implications of nanomaterials for the environment.

- In addition to its large centers and user facility investments, NSF's core programs and its Nanoscale Interdisciplinary Research Teams (NIRT) and Nanoscale Exploratory Research (NER) program announcements have resulted in a number of research grants related to addressing the impact of nanomaterials on the environment. Three examples are
 1. Nano Carbon Particles in the Atmosphere: Formation and Transformation. This project focused on development of theoretical and experimental methodologies to describe the formation and heavier hydrocarbons and particle inception, their growth, and transport in atmosphere. These methodologies are needed for study of fate and transport of nanomaterials in the environment.
 2. Response of Aquatic and Terrestrial Microorganisms to Carbon-Based Manufactured Nanoparticles. This research is investigating the effect of carbon-based manufactured nanomaterials on the ecology and toxicity of aquatic and soil microorganisms.
 3. Nanoscale Size Effects on the Biogeochemical Reactivity of Iron Oxides in Active Environmental Nanosystems. This group will study the size-dependence of biogeochemical processes in active environmental nanosystems. Active nanosystems comprising iron oxide nanoparticles and iron-reducing microorganisms influence natural biogeochemical cycles and can provide the basis for improved environmental remediation technologies. The study will include a quantitative kinetic analysis and modeling of surface coordination of adsorbed species and will focus on fundamental aspects of nanoparticle reactivity research.
- The Department of Defense supports research to enable physicochemical characterization and toxicology for water, air, and space environments and research to assess, avoid, and abate any adverse environmental or health impact from defense utilization of nanotechnology.

Research/Information Needs

Evaluate the potential for effects on the environment. Nanomaterials or their transformation products may generate indirect and unforeseen environmental effects, such as changes in pH or air quality, or photo-oxidative or catalytic effects on other chemicals in the environment. Additional research is needed to explore the effect of such factors on both biological and nonbiological environmental conditions.

Evaluate testing schemes for ecological effects. Research is needed to evaluate the current ecological effects testing schemes and test protocols for individual species (organisms, endpoints, exposure regimes, media, and analytical methods) in those schemes, to determine their applicability for regulatory decisions on potential effects of relevant nanomaterials and their byproducts. A variety of different types of tests will be needed to address potential effects of nanomaterials on relevant ecological receptors. These include traditional toxicity tests that are both short term (acute) and longer term (chronic), but may also involve the development of other innovative and novel tests based on the unique properties of nanomaterials. A better understanding of the distribution of nanoscale materials and their byproducts in ecosystems is needed to determine potentially affected compartments, species, and other effects that are not easily predicted in such complex systems. For relevant animal and plant ecological species, there is a need to better understand the ADME parameters for nanomaterials. There is also a need to better understand how structure-activity

4. Nanomaterials and the Environment

relationships can be developed or adapted for a broad range of ecological receptors including relevant aquatic and terrestrial species and what the major modes of action are for these receptors.

Understand exposure potential in aquatic systems. The propensity of aquatic organisms to bioaccumulate pollutants is likely to vary greatly across types of nanomaterials; knowledge of the factors that contribute to bioaccumulation would aid in risk management decisions. For example, is it possible to design nanomaterials to avoid bioaccumulation of them or their byproducts? Studies of nanomaterials could include evaluations of chemical and biotic factors likely to influence bioaccumulation and toxicity of nanoscale materials in aquatic systems. To address this, EPA uses persistence, water chemistry (e.g., dissolved organic carbon and particulate organic carbon), and biotic (lipid content and trophic level) characteristics when calculating national bioaccumulation factors for organic compounds (U.S. EPA, 2003).

Develop standardized sampling methods relevant to nanomaterials in the environment. It is not known whether (or to what degree) current sampling and analytical methods for estimating levels of materials or contaminants released into environmental media can be used for sampling and analysis of releases of nanomaterials. Investigations may address diverse types of environmental media: air, water, soil, sediments, plant matrices, and animal matrices (such as blood, bile, and whole body).

Identify the determining factors affecting the transport of nanomaterials in the environment. Some data from preliminary studies suggest that environmental transport mechanisms and partitioning for nanomaterials may differ from those for corresponding larger materials. Consequently, existing methods must be evaluated and perhaps new test methods developed.

Understand the transformation of nanomaterials under different environmental conditions. Chemical reactions such as oxidation, exposure to sunlight, or exposure to moisture may change some nanomaterials. Microbially mediated biochemical reactions also can be expected to change the electrochemical and other properties of nanomaterials. Resulting changes may influence the behavior of nanomaterials in indoor versus outdoor environments. Studying the transformation of nanomaterials by the environment requires a comprehensive assessment of reactive environments (such as indoor, outdoor, aqueous, dry, and various lighting environments).

Other important research questions concerning mechanisms by which nanomaterials may enter, remain, and move through the environment include

- What factors affect atmospheric long-range transport and deposition of nanoscale materials?
- What quantities of nanomaterials enter the environment from workplaces and consumer products?
- What factors affect the potential for nanomaterials, if released to either exposed soil or in a lined landfill, to migrate to groundwater and potentially reach general populations via drinking water?
- What factors affect the potential for these materials to be transported while bound to sediments or sludge in surface waters?
- How do aggregation, sorption, and agglomeration of nanomaterials affect transport processes?
- What factors affect the ability of nanomaterials to alter the mobility or reactivity of other substances in the environment?
- What biotic or abiotic processes affect persistence of nanomaterials in the environment or cause them to degrade? If they degrade, what are the byproducts and their characteristics?

4. Nanomaterials and the Environment

Possible Research Approaches

Approaches to ecological and environmental effects testing should include representative nanomaterials from the major classes of commercial products, particularly those that are most likely to be released into the environment. Current ecological effects testing schemes and associated protocols should be evaluated with respect to their applicability to nanomaterials (including order of tests and criteria for proceeding from one test to the next in relevant testing schemes; as well as considerations of organisms, endpoints, exposure regimes, media, and analytical methods employed for individual protocols). Research on model ecosystems such as microcosms and mesocosms could provide indications of relevant ecosystem compartments, parameters, and species. ADME parameters, structure activity relationships, and modes of action should be determined for appropriate terrestrial and aquatic environmental receptors.

As with any new material, research on nanomaterials in the ecosystem will benefit from interdisciplinary collaboration. Interdisciplinary research teams should assess the potential of nanomaterials to disperse to various environments, with an eye toward assessing any effects resulting from the exposure of potential biological receptors in these environments. Research solicitations cosponsored by several Federal agencies requiring teams of chemists, material scientists, geochemists, microbiologists, and civil and environmental engineers may be necessary to understand the complex and interwoven issues involved in environmental fate of these materials. In addition, considering the volume and breadth of information likely to be generated, coordination among government, academic, and industrial researchers will help validate research data and apply results.

To gain a complete picture of ecosystem habitats and alterations attributable to exposures to nanomaterials, it will be crucial to start with laboratory research and end with pilot field studies. In addition, fundamental information regarding the nature or the differences between specific nanomaterials and their macro counterparts will be useful. Where possible, research should also focus on combining analyses on a system level, to learn about the mode and duration of any nanomaterials' alteration of various ecosystems.

5. HEALTH AND ENVIRONMENTAL SURVEILLANCE

This area addresses research on the systematic collection, analysis, and interpretation of data obtained over time on human exposure to nanomaterials in the workplace and other indoor and outdoor environments; research to determine the presence of these materials or their byproducts in the environment; research on the determinants of exposures to support interpretation of limited or surrogate workplace and environmental data; monitoring of the health experience of individuals exposed to nanomaterials; and monitoring outcomes in habitats impacted by nanomaterials.

Health and environmental surveillance data are used to guide efforts to improve safety, health, and environmental protection and to monitor trends and progress. Health surveillance is a basic tool for Federal, state, and local public health and environmental protection activities. It can focus on the incidence of a specific adverse outcome to identify risk factors or on a specific risk factor to identify adverse outcomes. The information is used to characterize the extent of health and environmental problems, identify opportunities to prevent adverse effects, plan for delivery of services to mitigate the effect, and identify associations between adverse effects and possible causes that can serve as hypotheses for further research. Key to surveillance is the dissemination and use of data to protect health and the environment.

OCCUPATIONAL HEALTH AND EXPOSURE

To balance management of nanomaterial exposures, there must be consideration of possible unknown health effects that could occur despite caution in both the interpretation of existing toxicology information and in exposure mitigation measures. Health monitoring should be considered early in the nanomaterial development cycle for workers in selected applications where exposures are possible, even when controls for releases and exposures are in place. Many industrial firms already practice this approach. For nanomaterials, the emphasis of such monitoring programs should be on early detection of effects, and, where possible, should build on common properties across nanomaterial types.

Different work processes could produce substantially different exposures to nanomaterials. Workplace studies are under way for two primary purposes: to ascertain the nature and extent of current and emerging occupational exposures to nanomaterials, and to develop a comprehensive and scientifically sound occupational-health-protection strategy for nanomaterials. Information on typical exposure levels is important for risk analysis, prioritizing research, and planning protective actions to prevent similar exposures.

Selected Relevant Federal Government Actions

- The NIOSH Surveillance Program tracks occupational injuries, illnesses, hazards, and exposures (see www.cdc.gov/niosh/topics/surveillance/).
- The Bureau of Labor Statistics Injuries, Illnesses, and Fatalities (IIF) Program provides data on illnesses and injuries on the job and on worker fatalities (see www.bls.gov/iif/home.htm). It is intended to provide indicators of economic losses and does not collect medical diagnostic information.
- NIOSH has begun field research to inform the occupational safety and health community of the nature and extent of current and emerging occupational exposures to nanoscale materials.
- NIOSH is partnering with organizations to conduct field studies aimed at characterizing exposures to nanoscale materials through a number of different mechanisms, such as its Nanotechnology Field Research Team visits of manufacturing facilities (see

5. Health and Environmental Surveillance

www.cdc.gov/niosh/topics/nanotech/newsarchive.html#fieldteam), the Health Hazard Evaluation Program (www.cdc.gov/niosh/hhe/HHEprogram.html), and research collaborations.

- NIOSH has initiated research to
 - evaluate the generation and control of engineered nanoscale materials at nanomaterial manufacturing and processing facilities
 - determine exposure concentrations (by mass, number, and surface area) for workers working with various nanomaterials
 - evaluate exposure assessment tools for nanoscale materials
- NSF has funded researchers at the University of Minnesota to perform experimental and numerical simulation of the fate of airborne nanoparticles from a leak in a manufacturing process to assess worker exposure.

Research/Information Needs

Collect health information. Injuries, illnesses, and clinical findings from employees are useful in identifying sentinel events or an unusual pattern of health outcomes. A sentinel event is a single case of an unusual injury or illness that is suspected of being associated with exposure to nanomaterials. Health data can be collected from company medical records or through health history questionnaires. If toxicity testing or other information identifies a concern for a specific health outcome, the results of medical monitoring for early clinical evidence of the outcome can also be collected and analyzed.

Collect exposure information. Exposure information can be highly qualitative such as “ever exposed (yes/no),” semi-quantitative such as “estimated level, time exposed, or exposure frequency,” or quantitative such as “personal exposure monitoring data.” Exposure data must be linked to the individuals so that it can be used to place individuals into exposure categories. Misclassification of individual exposures would reduce the ability of surveillance to detect health effects by reducing the difference between high- and low-exposure groups. Quantitative exposure data reduces the chances of misclassification and improves the quality of health surveillance programs.

Understand workplace processes and factors that determine exposure to nanomaterials. How nanomaterials behave in processes and the workplace factors that determine the exposures to nanomaterials need to be investigated as a foundation for developing effective exposure classification strategies. Exposure monitoring will evolve over time as knowledge and technology improve. Information on the process, task, and location variables that determine exposure in workplaces can be used to help reinterpret old monitoring data in the light of new knowledge or to classify exposures in a workplace that has not been monitored.

Analyze injury and illness reporting. Evaluations of existing occupational injury and illness reporting programs are needed to determine the feasibility and utility of their use for identifying adverse outcomes associated with nanomaterials. The key question is whether the programs collect information that allow for the identification of events associated with nanomaterials.

Possible Research Approaches

Injury and illness reporting. Existing occupational injury and illness reporting programs may have the potential to provide information on adverse events associated with nanomaterials; however, these are generally passive surveillance programs that rely on reporting of events requiring medical care or identified on death certificates. Separate analyses of the data reported to these programs, with the goal of identifying events potentially associated with nanomaterials, would help ensure events are not missed. Individual companies or industry associations can voluntarily set up occupational injury and illness reporting systems that have a lower threshold for

5. Health and Environmental Surveillance

reporting and more detailed reporting. Analyses of injury and illness reporting systems could help identify sentinel events or patterns of events associated with nanomaterials that can be investigated to determine cause and prevent reoccurrence. Passive surveillance is generally ineffective in identifying long latency period health effects or health effects that do not cause an individual to seek medical attention.

Occupational exposure registry. Exposure registries allow for the analysis of the health and exposure data for possible associations. Employment processes generate records on job duties, locations, exposures, and health status that can be used to establish an occupational exposure registry. These records may be augmented with special medical and exposure monitoring studies if the data are not already being generated by company safety and health protection programs. Suspicious health events or patterns of events are investigated to identify possible associations with exposure. Proving causation generally requires additional study to establish the statistical significance of associations and a biological mechanism for observed health effects. Investigators usually must have access to medical records to code diagnoses to ensure actual rates can be compared to expected rates. Access to and protection of personal medical data must conform to medical confidentiality and privacy protection rules. Exposure-related data should be combined with other data sources, such as found in the Nanoparticle Information Library (www2a.cdc.gov/niosh-nil), and toxicity data to provide relevant information for risk assessment and risk management processes.

Cohort epidemiology studies. Hypotheses generated through surveillance or laboratory research can be investigated through studies that determine whether the incidence of a health effect among employees is elevated above expected rates. Individuals enter the studies on the basis of exposure and non-exposure. Population groups followed in an epidemiological study are often called cohorts. Cohort studies can be either prospective or retrospective and are used to determine if a health effect is associated with exposure and to quantify the relative risk associated with exposure.

Nested case-control epidemiology studies. Participants are selected based on disease status, cases with the health problem, and controls without. These groups are then compared to determine their actual exposure levels or the presence of other risk factors. Findings can be extrapolated to the population from which the cases and controls came. Risks are expressed as odds ratios that quantify the degree of risk associated with an exposure level or other factor. Nested case-control epidemiology studies often follow cohort studies to better understand the exposure levels or factors that caused an observed excess disease incidence.

PUBLIC HEALTH AND EXPOSURE SURVEILLANCE

Currently, little is known about the number, identity, health, or exposure levels of individuals who use nanomaterials or on people having close contact with those individuals (e.g., family members). Similarly, little is known about how nanomaterials are released into the environment and their effects on exposed populations. The lack of descriptive information complicates the planning and prioritizing of research and protective actions. Collecting and analyzing health and exposure data for individuals exposed to engineered nanoscale materials, their precursors, and byproducts could help characterize the extent of health risks and ensure that risks are not overlooked through sole reliance on animal model toxicity tests. Moreover, routine analysis and dissemination of health and exposure data can minimize the lag time in identifying potential problems and sharing lessons on preventing adverse events.

Selected Relevant Federal Government Actions

- The Centers for Disease Control and Prevention (CDC) coordinates with state and local health departments to operate a broad range of health surveillance projects. CDC's Toxic Substances

5. Health and Environmental Surveillance

and Disease Registry operate surveillance programs for environmental health effects (see www.atsdr.cdc.gov/about.html). Specifically, the National Report on Human Exposure to Environmental Chemicals provides an ongoing assessment of the U.S. population's exposure to environmental chemicals using biomonitoring. Biomonitoring is the assessment of human exposure to chemicals by measuring the chemicals or their metabolites in human specimens such as blood or urine (see www.cdc.gov/exposurereport).

- The CDC through the National Health and Nutrition Examination Survey collects information on environmental chemical exposures to the U.S. population (see www.cdc.gov/nchs/data/nhanes/nhanes_03_04/blood03_04.pdf).
- The FDA maintains post-marketing surveillance programs for foods, cosmetics, medications, and medical devices to identify adverse events that were not identified during the product approval process. Each center of the Agency maintains its own listings and websites, which can be accessed at www.fda.gov/nanotechnology.
- The Consumer Product Safety Commission (CPSC) operates an injury surveillance and follow-back system of a sample of hospital emergency rooms known as the National Electronic Injury Surveillance System to provide timely data on consumer product-related injuries occurring in the United States (see www.cpsc.gov/library/neiss.html).
- The EPA Ambient Air Monitoring Group coordinates collection and analysis of air quality data from various air monitoring stations (see www.epa.gov/air/oaqps/organization/aqad/aamg.html).
- The EPA Watershed Assessment, Tracking & Environmental Results program coordinates the routine collection, analysis, and reporting of water quality data (see www.epa.gov/waters/).
- The EPA has analyzed health studies, toxicological data, and exposure monitoring estimates for ambient particulate matter to assess their public health impacts (see cfpub.epa.gov/ncea/cfm/partmatt.cfm).
- The EPA's particulate matter risk assessments are a model for addressing questions concerning exposure, monitoring, and environmental fate, which would support similar assessments for engineered nanoscale materials. Ultrafine components of particulate matter (nanoscale particles) are a mixture of chemicals from combustion and natural sources, including gases that react with each other and precipitate to a solid state. Since similar chemical and combustion processes are being used to form first-generation engineered nanoscale materials, knowledge of ultrafine particulate matter may provide insight into dosimetry, fate, translocation, and physicochemical properties related to the toxicity of nanoscale engineered materials.

Research/Information Needs

Quantify nanomaterial exposure to the general population from consumer products, industrial processes, and products containing nanomaterials. Exposure assessment studies should be conducted to quantify any general population exposures to nanomaterials resulting from the use of consumer products. Nanomaterials may be released from these products, come in contact with humans, and be absorbed through various routes of entry (e.g., inhalation, dermal absorption) (Thomas et al., 2006). Data should be collected to determine any accumulation in and/or persistence of nanomaterials in the indoor environment; to characterize the exposure and identify changes that may occur to the nanomaterials (e.g., agglomeration); and to determine subsequent releases into the outdoor environment. The CPSC Chronic Hazard Guidelines (57 Fed. Reg. 4633), the EPA Exposure Assessment Guidelines (U.S. EPA, 1992), and other relevant guidance should be used as appropriate in evaluating nanomaterial exposures in the general human population.

Analyze injury and illness reporting. The evaluation of existing injury and illness reporting programs for consumer exposures is needed to determine the feasibility and utility of their use for identifying adverse outcomes associated with nanomaterials. As in occupational exposure

5. Health and Environmental Surveillance

reporting, a key question is whether the programs collect information that allow for the identification of events associated with nanomaterials.

Identify population groups exposed to engineered nanoscale materials. Groups potentially exposed to nanomaterials include patients, consumers, and neighbors of production or utilization plants. Targeting surveillance on a potentially exposed group—and sensitive populations within groups, such as people with pre-existing health problems—requires identification of group members. Demographic information is also collected to allow for comparison of the cohort's injury and illness rates to expected rates for a group with similar demographics. Keeping identifying information allows for longitudinal follow-up of long-latency health outcomes and notifying participants of findings that indicate actions they should take to protect their own health.

Collect health information. Injuries, illnesses, and clinical findings from members of the at-risk cohort are collected to identify sentinel events or an unusual pattern of health outcomes (see Occupational Health and Exposure above for additional description).

Collect exposure information. Exposure information can be highly qualitative such as “ever exposed (yes/no),” semi-quantitative such as “estimated level, time exposed, or exposure frequency,” or quantitative such as “biomonitoring data or prescribed medications.” Exposure data must be linked to the individuals in the at-risk cohort so that it can be used to place individuals into exposure categories (see previous section for additional description).

Possible Research Approaches

Injury and illness reporting. The existing injury and illness reporting programs described above for non-worker exposures may have the potential to provide information on adverse events associated with nanomaterials. (For further discussion of issues involved in such reporting systems, see Possible Research Approaches in the section above on Occupational Health and Exposure.)

Environmental exposure registries. Individuals are offered enrollment in environmental exposure registries if they are potentially exposed by living in impacted areas. Exposure registries analyze health and exposure data for possible associations. Proving causation generally requires additional study to establish the statistical significance of associations and a biological mechanism for observed health effects. Investigators usually must have access to medical records to code diagnoses to ensure actual rates can be compared to expected rates. Access and protection of personal medical data must conform to medical confidentiality and privacy protection rules.

An environmental exposure registry follows the health of individuals exposed to contaminated air or water. If locations where releases of nanomaterials result in exposure, monitoring can estimate exposure levels and the exposed individuals can be enrolled in programs that gather health outcome data.

Cohort and nested case-control epidemiology studies. Epidemiology studies could be used to identify health effects associated with exposure. (For further discussion of these approaches, see the section on Reducing Exposure in the Workplace in Chapter 6.)

ENVIRONMENTAL HEALTH SURVEILLANCE

Engineered nanoscale materials might enter the environment via effluents from large-scale manufacturing; use and disposal of personal care products; dispersive uses such as fuel additives; deliberate disposal; or transportation accidents. Nanomaterials might also be intentionally introduced into the environment in the process of pollution remediation. Nanoscale iron and palladium/iron particles are under investigation to remediate sites contaminated with hazardous chemicals such as trichloroethylene. Researchers have already tested some of these materials at

5. Health and Environmental Surveillance

sites (Mach, 2004; Zhang, 2003), but to date, little is known about the effects releases might have on the environment.

Selected Relevant Federal Government Actions

Currently, there are no Federal Government programs conducting surveillance of ecological health that focus specifically on nanomaterial releases or effects from them. However, there are a large number of programs at agencies such as EPA, National Oceanic and Atmospheric Administration, and the U.S. Geological Survey (USGS), as well as state programs that regularly monitor and report the condition of aquatic and terrestrial ecosystems. For example, at EPA, several programs, such as the EPA Watershed Assessment, Tracking & Environmental ResultS (WATERS) Program and the biennial state water quality monitoring reports are authorized by the Clean Water Act. The USGS National Water Quality Assessment Program, Toxics Substance Hydrology Program, and Contaminant Biology Program assess the health, or status and trends of contaminants in water and biota. These programs provide an infrastructure on which to build future efforts to monitor the impact of nanomaterials on environmental health. Such efforts must be built on a solid scientific basis and enabled by the types of research and information described below and in Chapters 2, 3, and 4.

EPA's Office of Research and Development is assisting with sampling and performance evaluation for a field test of nanoscale zero-valent iron at a U.S. Department of Defense site. The plans include monitoring the effects of the nanomaterials on bacteria that biodegrade contaminants on the site.

Research/Information Needs

Develop methods for measuring nanomaterial exposures in environmental matrices. Understanding potential environmental impacts from nanomaterial exposures begins with the means to quantify exposure. Development of environmental measurement methods should proceed in partnership with the evolution of toxicological understanding of exposure routes and bioavailability issues so that exposure monitoring methods can be targeted to the environmental media and chemical forms most relevant to understanding potential ecological risks (see also Chapter 2).

Establish environmental monitoring activities. Methods to monitor the environmental fate of nanomaterials should be developed to enable ongoing surveillance of air, water, soil, and sediments to establish the environmental exposures that occur as a consequence of nanomaterial use/release. (An example is monitoring at sites where nanoscale zero-valent iron is released into contaminated groundwater for treatment.) Where exposures exist, biological studies should be conducted to determine the effects of these exposures and the underlying mechanisms. Information on the type and amount of releases or changes in biota will help agencies prioritize questions that will benefit from further research. Disseminating summary information to nanomaterial industries and environmental protection agencies can promote early prevention activities.

Evaluate release scenarios most likely to create environmental exposures. This would be analogous to identifying susceptible sub-populations for human exposure; information on nanomaterial use and release must be combined with information on environmental fate and potential biological effects to determine where to target surveillance activities.

Determine environmental fate and effects following known or suspected releases. In cases where nanomaterials are used or disposed of in ways that create environmental releases, conduct focused studies to evaluate environmental fate. Where meaningful exposures exist, conduct studies to determine biological effects, if any, resulting from those exposures. Nanomaterials may affect not only the cellular processes of higher organisms, but also those of microbial communities that control organic decomposition, breakdown of contaminants, and other ecosystem services. Where

5. Health and Environmental Surveillance

possible, develop diagnostic tools to establish cause/effect relationships between nanomaterial exposure and biological effects.

Gain early knowledge of unanticipated effects to biota. Surveillance of biota involves the routine collection, counting, and evaluation of specimens in habitats affected by nanomaterials to identify abnormalities, population changes, or other effects requiring further investigation. Information on contamination in air, water, soil, sediments, and biological specimens related to engineered nanoscale materials, their precursors, or byproducts would be useful in identifying habitats to be monitored. The goal is to provide a “safety net” to identify circumstances where the environmental transport and behavior of, or the ecological effects of, nanomaterials are different from what would be predicted from existing knowledge.

Possible Research Approaches

Understanding emission sources and levels of concentration. It is common to monitor discharges from facilities to demonstrate compliance with environmental protection standards. Facilities researching, developing, and producing nanomaterials may need to monitor their air and water emissions to meet a regulatory requirement, or may be willing to conduct this monitoring voluntarily. Such data provide information on the amount of material being emitted and can be used to estimate concentration levels in the surrounding environment. Monitoring methods similarly would need to be developed for nanomaterials.

Understanding levels of concentration and trends for nanomaterials in ambient air. Data from air-monitoring stations near nanomaterial generating facilities might be able to provide information on releases of engineered nanoscale materials, their precursors, and byproducts if monitoring methods can be developed. Data on air quality from the EPA Ambient Air Monitoring Group’s nationwide system of air-monitoring stations could be valuable inputs to research in this area.

Understanding levels of concentration and trends for nanomaterials in surface and groundwater. The EPA Watershed Assessment, Tracking & Environmental Results (WATERS) Program coordinates the routine collection, analysis, and reporting of data on water quality from local, state, and Federal water quality monitoring programs. Information from water quality monitoring stations near nanomaterial generating facilities or near watersheds potentially affected by nanomaterial facility operations might be able to provide information on releases of engineered nanoscale materials, their precursors, and byproducts if monitoring methods can be developed.

Collecting data from existing monitoring programs. On large government-owned military, industrial, and testing sites, such as Superfund sites, with activities involving hazardous materials, surveys are often performed on terrestrial and aquatic species to identify possible effects of their operations. Data from such routine monitoring programs, especially at sites that have used nanoscale environmental remediation methods or that are currently hosting other nanotechnology activities, might be used to identify effects of nanomaterials. Data collected by ecologists and others monitoring natural environments for other purposes could also be useful in understanding possible effects of nanomaterials at the ecosystem level.

6. RISK MANAGEMENT METHODS

This area comprises research on methods for risk management of nanomaterials, including research on methods to reduce exposures to potentially hazardous nanomaterials; to improve procedures for risk and accident avoidance; to improve work practices, engineering controls, and protective equipment; and to develop procedures for life cycle assessment and improved understanding of potential impacts over the full product life cycle, from raw material extraction through disposal and/or recycling.

RISK MANAGEMENT APPROACHES

Once identified, risks traditionally are managed by taking one or more steps, beginning with simply replacing the use of a potentially hazardous material or process with one that is less so. As noted earlier in this document, some nanomaterials may offer safer alternatives to known hazardous materials in certain applications. Other methods for risk management involve reducing exposure, which includes protecting workers in manufacturing facilities, as well as control of releases from such facilities, from transportation of nanomaterials, or from spills or accidents involving these materials. Potential exposure of the public to nanomaterials in consumer products must be considered for both the use and the disposal, or recycling, of products containing nanomaterials.

The research identified throughout this document will contribute to risk assessment and will guide risk management decisions. Current risk management techniques, even those used to minimize exposures to fine or ultrafine particulate matter, must be evaluated for their appropriateness in addressing the new uses and properties of engineered nanoscale materials.

An initial priority is evaluation of risk management techniques for workers in manufacturing and research facilities and for their potential applicability to larger populations. Uncertainties regarding potential hazards in handling specific engineered nanoscale materials have led NIOSH and the Occupational Safety and Health Administration (OSHA) to consider risk management approaches, such as control banding or risk management toolkit, that do not rely on traditional exposure-limit-based approaches. Such approaches are designed to allow unhindered innovation, while simultaneously ensuring safety and health of the public and the environment. There may be other approaches for managing potential exposures of workers or others. Risk management approaches for nanomaterials will need to be evaluated as researchers continue to assess potential hazards and risks.

Selected Relevant Federal Government Actions

- In December 2004, EPA's Science Policy Council formed a Nanotechnology Workgroup to identify science policy issues related to nanotechnology and the environment. The workgroup determined that a white paper would be the appropriate product to provide information for EPA managers and to communicate the science of nanotechnology, science policy, and research issues of importance to EPA. The EPA Nanotechnology White Paper was then drafted, underwent external peer review in the spring of 2006, and will be released as a final EPA document by the end of 2006. The external review draft of the White Paper may be found at www.epa.gov/osa. The risk management chapter of the EPA White Paper describes the framework and approach the agency envisions for managing the potential risks associated with nanomaterials. It includes discussions of environmental stewardship and pollution prevention, as well as authorities under EPA's existing statutes addressing protection of the air, water, and land.

6. Risk Management Methods

- EPA held a public meeting on June 23, 2005, to discuss a potential voluntary pilot program for reporting information pertaining to existing chemicals that are nanoscale materials and the information needed to adequately guide the conduct of the pilot program. Following the meeting, EPA requested that the National Pollution Prevention and Toxics Advisory Committee (NPPTAC) consider providing input to EPA on options for elements of EPA's approach to such a program. NPPTAC considered comments received during the June EPA public meeting and held additional public meetings to obtain broad stakeholder input. An Overview Document on Nanoscale Material, which presented the NPPTAC analysis and views of a framework, was provided to EPA for consideration of an approach to nanoscale materials.
- FDA has formed an internal task force that will identify and recommend ways to address any knowledge or policy gaps that exist so as to better enable the agency to evaluate possible adverse health effects from FDA-regulated products that use nanotechnology materials. The task force will chair a public meeting on October 10, 2006, to help FDA further its understanding of developments in nanotechnology materials that pertain to FDA-regulated products.
- NIOSH's Nanotechnology Research Center conducts research into the implications and applications of nanoscale materials for work-related injury and illness, including assessment and development of risk management techniques (www.cdc.gov/niosh/topics/nanotech/). NIOSH's Nanotechnology Field Research Team partners with nanomanufacturers in assessing effectiveness of risk management practices in the workplace to reduce exposures to nanomaterials.
- NIOSH and OSHA are active in evaluating the applicability of control-banding approaches to risk management of nanomaterials. NIOSH defines control banding as "a process in which a single control technology (such as general ventilation or containment) is applied to one range or band of exposures to a chemical (such as 1–10 mg/m³) that falls within a given hazard group (such as skin and eye irritants or severely irritating and corrosive materials)" (see www.cdc.gov/niosh/topics/ctrlbanding/). The importance of this approach was recognized at the October 2004 International Symposium on Nanotechnology and Occupational Health (see www.hsl.gov.uk/capabilities/nanosymrep_final.pdf).
- NIOSH conducted a national control-banding workshop in 2005 to discuss planning and implementing control-banding strategies in the United States.
- NSF supports fundamental research on decision making, risk, and uncertainty as part of its Human and Social Dynamics portfolio. This research will yield insight into decision-making processes, loss and mitigation models, and risk perception that are widely applicable to managing the risks associated with emerging technologies, including nanotechnology

Research/Information Needs

Evaluate the appropriateness and effectiveness of current risk management approaches for identifying those nanomaterials with the greatest potential risks. Parameters for grouping nanomaterials by hazard and exposure potential will help in the evaluation of risk management frameworks to determine their effectiveness.

Evaluate the opportunities for greatest potential risk reduction through minimizing hazard or exposure to nanomaterials. Factors influencing the potential for exposure to, or contamination by, nanomaterials need further investigation.

Evaluate accepted risk management approaches for nanomaterials. The suitability of control banding and other risk management approaches need to be further evaluated with respect to working with nanomaterials in situations where insufficient information is available to apply traditional exposure-limit-based control strategies. Banding or tiered approaches to risk

management for nanomaterials and byproducts that incorporate both the potential hazard and level of exposure should be further evaluated for the ability to effectively reduce risks to human health and the environment.

REDUCING EXPOSURE IN THE WORKPLACE

Because nanomaterials are already being commercially produced, attention should be given now to data that support risk management decisions for the workplace. Methods for controlling potential exposures to airborne and liquid materials in the workplace (perhaps applied hierarchically) include process design and engineering controls such as containment and ventilation systems, work practices, administrative actions, and personal protective equipment. The adequacy of exposure controls for “free” (not fixed in a matrix) nanomaterials should be researched further, because potential for exposure to free nanomaterials is greater than for embedded nanomaterials.

PROCESS DESIGN AND ENGINEERING CONTROL

Process designs and engineering controls have been important elements for risk management in the realm of toxic industrial chemicals. Similarly, storage, containment, and ventilation all contribute to the exposure-management strategy. In order to evaluate the efficacy of workplace air supply systems for nanomaterials, more research is needed on whether nanomaterials accumulate in recirculated air. Suspension of materials in air depends on general persistence, size, surface charge, and other factors. The suspension of different engineered nanoscale materials is expected to vary widely. However, because of the small size and low mass of all nanomaterials, those that do become suspended in air are likely to behave in a similar way to gas molecules, moving randomly as a result of Brownian motion. In this regime, nanomaterials can diffuse rapidly and remain suspended in air for an extended period of time. Conventional engineering controls for separating an exposure source of engineered nanoscale materials in this “gas phase” include various combinations of containment and ventilation systems such as

- total enclosure of the process
- partial enclosure with local exhaust ventilation
- open areas with active exhaust ventilation
- general ventilation

Selected Relevant Federal Government Actions

- NIOSH is conducting studies to evaluate the effectiveness of engineering controls to reduce exposure to engineered nanoscale materials, and it is interacting with industry groups that are addressing the same issue (www.cdc.gov/niosh/topics/nanotech/strat_plan.html). For example, one of the goals of the Nanoparticle Occupational Safety & Health Consortium is to evaluate equipment and materials to protect workers or researchers (www.nanotechproject.org/index.php?id=18&action=view&project_id=741).
- Several NSF awardees are developing instrumentation for monitoring nanoparticles, which could be useful for ensuring the proper operation of control technology in factories. Examples include instrumentation for *in situ*, real-time, high-resolution measurements of nanoparticle size distributions
 - chemical composition of nanoaerosols
 - Laser Doppler Velocimetry (LDV) in synchronous AC electric and acoustic fields, to determine the size and charge of nanoparticles

6. Risk Management Methods

- These technologies could also be used to monitor nanoparticle emissions in the environment, providing critical information for the design and implementation of mitigation strategies where needed.
- An NSF-supported Nanoscale Interdisciplinary Research team is investing ceramic membranes for filtration of nanoparticles, which could be an important control technology for manufacturing processes involving aqueous nanoparticles.

Research/Information Needs

Improve understanding of the unique challenges for process design and engineering control systems applied to engineered nanoscale materials in air. This research should evaluate the effectiveness of existing and novel engineering-control techniques for engineered nanoscale aerosols, and explore process design and engineering controls that govern the release of engineered nanoscale materials to air, control their removal from air, or control their exposure to air.

Possible Research Approaches

Efforts should focus on developing criteria for selection, design, and testing processes and for engineering control techniques to reduce risk of occupational exposure to nanomaterials.

There may be methods for storing nanomaterials that would minimize unintended exposures or the likelihood of unintentional release of nanomaterials. Nanomaterials might be confined in liquid suspensions or fixed within a solid matrix, such as pellets (an approach currently being used by some nanomaterials manufacturers), without loss of useful properties. Careful attention to the design of production processes also might minimize exposures from fugitive releases during handling, recycling, and disposal.

Manufacturing processes also could be designed to avoid use of hazardous elements and chemicals in order to minimize the potential to cause harm to the environment or workers.

WORK PRACTICES

Conventional work practices and administrative controls used to control exposure to particulate matter include

- control or reduction in number of workers and exclusion of others
- reduction in periods of exposure
- regular cleaning of walls and other surfaces
- prohibition of eating and drinking in contaminated areas

Approaches to Safe Nanotechnology: An Information Exchange with NIOSH is a draft guidance and discussion document that outlines current knowledge about the occupational health and safety implications and applications of engineered nanoscale particles, using internal and external research data (www.cdc.gov/niosh/topics/nanotech/safenano/). It also offers interim recommendations on occupational safety and health practices in the production and use of nanomaterials, including mitigation of potential workplace exposures. These interim recommendations will be updated and revised as newer data become available.

Selected Relevant Federal Government Actions

NIOSH maintains interim guidelines for safe work practices and interim administrative controls in the nanomaterial manufacturing and processing environment that are each updated as further information is developed through focused monitoring and other research efforts in collaboration with industrial and academic partners.

Research/Information Needs

Understand the role and effectiveness of work practices and administrative controls in reducing exposures to nanomaterials as exposure and hazard information evolve. There is need to evaluate further whether unique properties of free engineered nanoscale materials (e.g., unique aerodynamic properties and propensity to agglomerate) require the development of novel work practices and administrative controls.

Possible Research Approaches

Research approaches could include continued collaborative efforts to address research gaps identified in interim recommendations on occupational safety and health practices in the production and use of nanomaterials.

PERSONAL PROTECTIVE EQUIPMENT

No studies on testing the effectiveness of personal protective equipment (PPE) against nanomaterials have been published. Some potentially useful existing guidelines include

- OSHA 3143 (1998) describes industrial hygiene practices and the prudent use of PPE.
- Existing standards on the penetration of liquid-borne contaminants through protective clothing may provide some insight on protection factors for nanomaterials.
- ASTM standard F1671-03 specifies the use of a 27 nm bacteriophage to evaluate the resistance of protective clothing materials to penetration by blood-borne pathogens.

No filtration system can remove completely airborne particles from air streams. Even High Efficiency Particulate Air (HEPA) filters designed to remove 99.97% of the particles whose sizes are the hardest to remove (typically around 300 nm) will allow a very small amount of aerosol to pass through. Furthermore, the properties of both the filter (e.g., fiber size, thickness, microstructure) and of the nanomaterials (e.g., surface charge, surface chemistry, geometrical parameters) determine the effectiveness and performance of a particular filter.

NIOSH certifies particulate respirators by challenging them with sodium chloride aerosols with a count median diameter of 75 nm or dioctyl phthalate aerosols with a count median diameter of 185 nm [42 CFR Part 84.181(g)], which research has found to be in the most penetrating particle size range (Stevens, Moyer, 1989). Larger particles are collected more efficiently by impaction, interception, and settling, whereas smaller particles (down to at least 2.5 nm) are collected more efficiently by diffusion or electrostatic attraction (Lee, Liu, 1982).

As nanomaterials get as small as the diameters of individual molecules (a few nanometers in diameter and below), more efficient filter penetration is anticipated, comparable to penetration of gases, due to a phenomenon called thermal bounce. Studies also have shown good collection efficiency for liquid droplets in high-efficiency filters for particles down to 4 nm in diameter (VanOsdell et al., 1990). A recent review of manufacturing techniques suggests that most engineered nanoscale particles are larger than 20 nm, or that they quickly agglomerate into larger particles, making them more likely to be collected by filters (www.hse.gov.uk/research/rrhtm/rr274.htm). Nonetheless, some researchers have expressed concern that nanomaterials may be subject to thermal bounce, which may cause them to bounce from filter fibers rather than stick to them, and thus pass through the filter.

Well-designed mask filters also must incorporate a tightly fitting face seal or a well-designed filter housing, so that stray particles cannot pass around the filter and enter into inhaled or exhaust air. Work by researchers at the U.S. Army Research, Development and Engineering Command on a headform showed that leakage around a mask (i.e., simulated respirator fit factor) measured using sub-micrometer aerosol challenges (0.72 μ m polystyrene latex spheres) was representative of vapor

6. Risk Management Methods

challenges such as sulfur hexafluoride (SF₆) and isoamyl acetate (IAA) (Gardner, Hofacre & Richardson, 2004). Having been performed on sub-micrometer particles, these studies are inconclusive with regard to implications for nanomaterials.

Selected Relevant Federal Government Actions

- The NIOSH Respirator Selection Logic (www.cdc.gov/niosh/docs/2005-100/) suggests consideration of the following when selecting an appropriate respirator:
 - physical, chemical, and toxicological properties of the contaminant
 - NIOSH Recommended Exposure Limit (REL)
 - or when no REL exists, OSHA Permissible Exposure Limit (PEL)
 - other applicable (occupational) exposure limits

Presently, data are sparse on engineered nanoscale materials relative to the first criterion. However, in 2005, NIOSH posted for public review a draft *Current Intelligence Bulletin: Evaluation of Health Hazard and Recommendations for Occupational Exposure to Titanium Dioxide*, which sets new RELs for nanoscale titanium dioxide at 0.1 mg/m³ (www.cdc.gov/niosh/docs/preprint/tio2/). At the time of this document's publication, this remains the only proposed occupational exposure limit for nanomaterials.

- In 2005, NIOSH awarded a contract to scientists at the University of Minnesota for a laboratory study to examine the efficacy of filters for selected engineered nanoscale particles. In this study, the researchers observed that penetration of nanoparticles through filter media decreased as particle size decreased down to 3 nm due to electrostatic and other forces that attract small particles to the filter media, as expected by traditional filtration theory (Pui and Kim, 2006). No evidence for thermal rebound of nanoparticles in the size ranges 3–100 nm was found. NIOSH plans to continue studying the nanoparticle collection efficiency of NIOSH-certified respirators to validate these findings.
- NIOSH and other Federal partners are also working with industry to evaluate the efficacy of current personal protective equipment against nanoscale material exposures, even though the PPE may not have been specifically designed to protect against nanoscale particulates.
- An NSF exploratory research project is examining the use of fractal nanoagglomerates as new media for HEPA filters.

Research/Information Needs

Understand the efficacies of PPE against nanomaterials as exposure and hazard information evolve. This research would involve evaluating filtration, filter-housing and face seal, and protective clothing efficiency down to the lower range of nanomaterial diameters (<10 nm).

Develop filters and fabrics with improved capturing and regenerating/self-cleaning capabilities. Nanomaterial applications offer tremendous opportunities to improve occupational safety and health through development of safety equipment with enhanced characteristics.

Possible Research Approaches

Protocols for testing PPE and respirators to determine effectiveness against exposure to nanoscale particles should be evaluated and developed where appropriate. Specifically, respirator recommendations for nanoscale aerosols, including determining protection factors and evaluating tests for proper fit, would enable significant advances in the area of nanomaterial risk management.

MINIMIZING ENVIRONMENTAL EXPOSURE AND HAZARD

Prudent strategies should be explored as frameworks to mitigate environmental exposure to nanomaterials if hazards are identified for specific materials. Such strategies might include

reducing releases to the environment, improving waste treatment, designing nonpersistent nanomaterials, and selecting more environmentally safe alternatives. Those topics are detailed in other sections of this document. Research should explore both conventional techniques and novel strategies yet to be identified.

Reducing environmental impacts can be achieved by a variety of means, including

- reducing industrial releases
- avoidance of and preparation for spills and other accidents
- creating and using materials to minimize toxicity potential
- designing products that minimize potential exposures to humans and the environment
- engineering materials that degrade into more benign compounds when released into the environment

REDUCING INDUSTRIAL RELEASES

Manufacturing processes may result in releases of nanomaterials to the air, water, or land. It must be determined whether potentially toxic nanomaterials are released and the levels of such releases. Where releases occur, the first and easiest step toward minimizing contamination of the environment is through reducing the levels of nanomaterials released at the source. Research is needed to explore techniques to limit emissions to the air as well as in effluent discharge. Research on the possible hazardous character of solid wastes from nanomaterial manufacturing also is needed, as is research on the best methods to dispose of any relevant remaining manufacturing wastes, in general. Research is also needed to determine if disposal and degradation of consumer products could result in the release of nanomaterials into the environment, requiring attention to controls for landfills, incinerators, and recycling facilities. Research should explore “green” designs for nanomaterial-derived products to limit the persistence of hazardous nanomaterials in the environment over their life cycle. Life cycle assessment efforts (covered later in this chapter) will complement these efforts.

Selected Relevant Government Actions

- EPA has funded over 40 projects through its STAR research grants program and Small Business Innovation Research program, focused mostly on applications of nanotechnology to detect, prevent, treat, or remediate conventional pollutants. A very limited number of studies have addressed pollution prevention or control in the nanomaterial manufacturing or nanoproduct manufacturing process itself. Information on the EPA projects is available at www.epa.gov/ncer/nano.
- NSF has also funded several studies of environmental, health, and safety aspects of nanomanufacturing, along with a large number studies on the application of nanotechnology to detect or remediate conventional pollutants. One example of NSF’s “green manufacturing” efforts is a Nanoscale Interdisciplinary Research Team that is developing solvent-free techniques to enable environmentally benign manufacturing of high-surface-area nanostructured composites. Further examples of NSF-sponsored EHS awards are available at www.nsf.gov/crssprgm/nano/7a_fy2005_env_nsfweb_06_0223.xls.
- The National Nanomanufacturing Network (NNN), led by the NSF-sponsored Center for Hierarchical Nanomanufacturing, includes health and industrial hygiene aspects of nanotechnology as part of its “Nanomanufacturing and Society” activities.

Research/Information Needs

Determine whether any residual manufacturing wastes of concern are being created and, if so, which processes are associated with such wastes. Some nanomaterial production processes

6. Risk Management Methods

are believed to produce little if any waste. Other processes, however, may produce waste. Sampling manufacturing emissions and effluent releases is necessary to determine if wastes are generated that are associated with nanomaterial production or utilization.

Where wastes of concern are being produced, determine the best methods for waste disposal. Information is needed on the ability of existing technologies and possible alternative technologies to capture or mitigate nanomaterial releases. Particular properties of nanomaterials that determine their potential for capture should be identified. Based on these properties, new control technologies can be developed. Properties of solid wastes from nanomaterial manufacturing that may cause them to be considered hazardous waste also should be identified.

Understand and develop manufacturing approaches that minimize environmental impact through “green design” principles. In a sense, this is “beginning with the end in mind.” Research is necessary to investigate integrating the technological processes into the manufacturing processes that will reduce the potential for ultimate release of nanomaterials into the environment. This is consistent with principles applied in other industrial chemical synthesis processes.

Possible Research Approaches

Studies would generally focus on technologies for removing/disposing of engineered nanoscale materials from emissions and effluents, concentrating on certain particle types or sizes thought to be potentially hazardous. In the long term, research could explore alternative technologies tied to specific nanomaterial properties, such as size, structure, and reactivity.

“Green” manufacturing research strategies need to be developed in conjunction with industry to conduct such research effectively and to address the processes with the highest levels of potential releases or hazard.

CONTAINING SPILLS

Materials may spill during manufacture and use. Conventional methods for controlling spills are generally designed for, among other things, the spilled material’s physicochemical properties, toxicity, and potential adverse effects to human health and the environment. Guidelines for designing processes and equipment for preventing and containing spills, as well as procedures for risk management, can be found in a number of references (AIChE, 1988).

Regulatory authorities have accepted the effectiveness of various spill mitigation systems for laboratories and manufacturing plants to address known chemical/material hazards. These systems range from large dikes around storage tanks, along with associated pumps and secondary storage tanks, to absorbents designed for specific hazardous chemicals.

Selected Relevant Government Actions

The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) provides the Federal framework to respond to oil, chemical, biological, and radiological releases to the environment, which encompass both accidental and intentional releases. The NCP is contained in regulation at 40 CFR 300 and is administered by the EPA. The NCP supports the National Oil and Hazardous Substances Response System (NRS) with planning, coordination, and direct preparedness activities by EPA for inland areas and the U.S. Coast Guard for the coastal zone. Other Federal agencies, along with state and local officials, support the two lead agencies under their appropriate jurisdictions. Although EPA does not currently have in place a program specifically to address risk management for wastes containing nanomaterials, existing programs would allow flexibility for future efforts.

Research/Information Needs

Develop spill mitigation technologies and risk management procedures specific to nanomaterials. There are no standardized technologies—and limited risk management procedures—explicitly designed to control spills of nanomaterials. Until such technologies and procedures are available, nanomaterial manufacturers may benefit from conventional spill mitigation plans and technologies, possibly with modification. In the long run, proper characterization of nanomaterials is necessary to develop specific containment technologies and procedures.

Possible Research Approaches

Both short-term and long-term approaches to developing spill containment and mitigation strategies should be considered. At the outset, a study could survey existing risk management practices and control technologies in spill mitigation for conventional materials, to evaluate their potential applicability to nanomaterials.

A parallel research agenda could evaluate new methods and equipment designed specifically for minimizing and containing spills of nanomaterials. Specific questions that could be considered include

- Can current conventional technologies and risk management procedures for spills be used or adapted to prevent and contain nanomaterial spills?
- Are existing methods that use collectors (i.e., vacuum systems) with HEPA filters effective to clean up a spill of nanoscale solids? If not, would a wet vacuum system work?
- How would cleanup systems then be handled? What determines the disposition of the accumulated nanomaterial?
- What PPE would be suitable for use by operators during spill mitigation?
- What unique procedures might be necessary to deal with nanomaterials dispersing and settling on various types of surfaces/equipment?

PREPARING FOR ACCIDENTS RELATING TO COMBUSTION AND REACTIVITY

Some nanomaterials have displayed exceptional energetic release. For example, reactions (thermites) of nanoscale Al and MoO_3 have been shown to ignite over 300 times faster than corresponding micrometer-scale material (Granier, Pantoya, 2004). Nanoscale combustible material could present a higher risk than a coarser material of similar quantity (Institute of Occupational Medicine, 2004). Presently, there is insufficient information on the explosion risk associated with nanoscale powders to enable reasonable risk predictions. Based on what is known of other “inert” materials that become dispersed in air (e.g., explosive risks of powders or flours), or the increased hazards of aerosolized flammable liquids (e.g., gasoline), the risks with significant amounts of nanomaterials may be nontrivial. Systems of codes, standards, and industry practices exist to provide both the educated workforces and the highly engineered preventive and containment equipment needed to reduce the likelihood or consequences of severe accidents.

Research/Information Needs

Understand factors influencing flammability and reactivity. The results of flammability and reactivity testing in both bulk and nanoscale versions of the same material could be collected and analyzed for unusual or conflicting results that require further investigation.

Discern trends in effects or causality in accidents or other incidents that may relate to the sizes or novel properties of engineered nanoscale materials. The goal of accident and incident investigations and reporting is to identify the root cause of unplanned adverse events so that recommendations for actions that will prevent recurrence can be developed and communicated.

6. Risk Management Methods

Industry-wide voluntary reporting of lessons learned from less serious accidents and minor incidents has been a highly effective method of improving risk management within the commercial aviation, nuclear, and other high-hazard industries.

Possible Research Approaches

A research program should be designed to systematically investigate the physical and chemical properties of classes of nanomaterials related to safety issues such as fire and explosion. The program also should include research on fire suppression of nanomaterials.

NANOMATERIALS IN THE TRANSPORTATION SYSTEM

The Hazardous Materials Regulations (HMR) (49 Code of Federal Regulations Parts 172–180) defines a hazardous material as a substance or material that the Secretary of Transportation has determined is capable of posing an unreasonable risk to health, safety, and/or property when transported in commerce. Materials listed in the hazardous materials table (49 CFR 172.100) or those that meet the defining criteria established in the HMR (49 CFR 173) are hazardous materials in transportation. Some nanomaterials could meet the Department of Transportation (DOT) definition of a hazardous material. DOT requires that persons who offer a hazardous material into the transportation system determine the hazard class or division, select proper packaging, package the material in accordance with package manufacturer's instructions, and communicate the hazards via shipping papers, labels and markings, and placards when required. Should a nanomaterial require packaging not covered under the HMR, the person who offers the material may submit a request for a special permit from DOT. A special permit is a document that authorizes a person to perform a function that is not currently authorized under the authority of the HMR, such as using alternative packaging.

Research/Information Needs

Fully characterize the nanomaterial to determine its properties and allow for an accurate determination and classification if it is a hazardous material. This may result in establishing a unique proper shipping name and United Nations (UN) identification.

Identify and evaluate the appropriate packaging requirements. This research would evaluate the efficacy in maintaining proper package integrity to prevent reasonable chance of release or ignition of the nanomaterial.

Determine if there should be any limitations or restrictions when using certain modes of transportation. This research will determine if certain materials affect the operation of the vehicle or the transportation environment.

Determine how best to communicate the hazard to the emergency response community under real-world accident scenarios. This supports a broader research need to evaluate the efficacy of existing first responder techniques and develop appropriate guidance for inclusion in the DOT Emergency Response Guidebook.

LIFE CYCLE ASSESSMENT

In order to responsibly manage environmental and human health impacts from nanomaterials, there is a need to better understand potential impacts over the full product life cycle, from raw material extraction through disposal and/or recycling. Life cycle assessment (LCA) is a useful approach for such “cradle to grave” evaluation of both the impacts of the nanomaterials themselves and the impacts from the consumption of other resources (e.g., energy and materials) in the extraction, production, delivery, packaging, use, and disposal of the materials and products.

Life cycle research, accordingly, focuses on the evaluation of resource use and the potential health and environmental effects of nanomaterials and nanomaterial-based products from the gathering of raw materials through the final disposition of those products.

Currently the life cycle impacts of nanomaterials are generally unknown. The environmental impacts of nanomaterials (and their degradation products) may be different from bulk materials, given the importance of size-related phenomena for nanomaterials. This is important to consider at all life cycle stages, but particularly at the use and disposal stages. Thus, the initial focus of LCA studies might be to address those nanomaterials life cycle stages that might differ in specific ways from those of bulk materials.

LCA studies generate an inventory of resources consumed and materials and chemicals emitted over a full product life cycle. This information can be used to identify human and ecological exposure potential based on the use, recycling, and disposal of products, and when, where, and how those exposures could occur. The information also can help to identify potential human health and ecological effects.

LCA studies are often comparative, evaluating the different impacts associated with comparable products or different ways of producing materials. LCA studies may be used to identify and target opportunities for risk management through materials selection, product design, manufacturing, process engineering, and/or recycling processes for overall life cycle environmental improvement.

A complete LCA requires a large amount of data and can be both time-consuming and costly. It requires data that may be unavailable for a rapidly developing sector, such as nanotechnology. Therefore, it may be important to develop new streamlined LCA approaches that incorporate estimation techniques and can intelligently handle uncertainty. Much of the data needs identified in the Chapter 2 subsection on Analytical Tools and Methods will be important to LCA studies. An inventory of nanomaterials and their uses, as well as databases of nanomaterial properties and effects, will greatly enhance work in this field, as will nanomaterial monitoring, environmental surveillance, and toxicity assessments, which are discussed elsewhere in this document.

In addition, material flow analysis (MFA) can be used to partition and understand the economy-wide cycles and ultimate fate and associated potential impacts of a given nanomaterial and the products they form. MFA is defined in different ways, but generally it is an analysis that describes the flow of materials into, within, and out of a system. MFA is particularly useful for nanomaterials to understand and partition the likely ultimate disposition of a given nanomaterial. Quantitatively estimating the economy-wide flow of the nanomaterial will illuminate how much is likely “lost” during manufacturing, dispersed during use, incinerated after use, recycled, etc. This, in turn, will highlight likely human and ecological exposure pathways and help to identify preventive strategies.

Selected Relevant Federal Government Actions

- Scientists from a number of Federal agencies are working with the International Life Sciences Institute, Health and Environmental Sciences Institute on a Nanomaterial Life Cycle Assessment team that will apply LCA methodology to products that contain nanomaterials. The assessment team will attempt to explore the ultimate fate of nanomaterials in the environment. Their efforts will include the evaluation of the inputs and outputs of materials, and the associated environmental and human health impacts from specific nanomaterials all the way from acquiring raw materials and manufacturing products through consumer use and disposal (www.hesiglobal.org).
- The EPA STAR Program has funded four research grants addressing life cycle assessment: Implications of Nanomaterials Manufacture and Use; Development of a Methodology for Screening Sustainability; Environmental Implications of Nanotechnology; Life Cycle Analysis

Approach for Evaluating Future Nanotechnology Applications; and Evaluating the Impacts of Nanomanufacturing via Thermodynamic and Life Cycle Analysis.

- NSF and EPA funded a study of manufacturing processes for five nanomaterials, including quantum dots, carbon nanotubes, and buckyballs, comparing their potential environmental and health risks with other common industrial processes. (See www.eurekalert.org/pub_releases/2005-10/ru-snp100405.php and cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/6156/report/F.)
- USGS conducts materials flow analyses of metals and industrial minerals in commerce (minerals.usgs.gov/minerals/mflow/) and collects statistics on production, use, and recycling of these materials through its Minerals Information Team.
- An NSF Nanoscale Exploratory Research project is developing risk scenarios for the full life cycles of three types of nanoparticles currently manufactured in multi-ton quantities: endohedral metallo-fullerenes, titania nanoparticles, and carbon nanotubes. The project's broad interdisciplinary approach, including toxicity studies, life cycle analysis, hierarchical holographic modeling, and assessment of the existing regulatory framework, will serve as a model for identifying environmental impacts and risks of nanomaterials.
- Another NSF grantee is using life cycle inventory (LCI) and life cycle assessment (LCA) methods to evaluate the environmental footprints of nanomanufacturing technologies.

Research/Information Needs

Understand how LCA may be suitable and adaptable to engineered nanomaterials. LCA techniques may need to be modified for nanomaterials. To determine this, LCA practitioners will need to become familiar with engineered nanoscale materials, how they differ from bulk compounds, as well as how they are likely to be manufactured and where they are likely to be used. Similarly, nanomaterials researchers will need to become familiar with the requirements and data needs of LCA practitioners.

Understand the use of nanomaterials in products. Adequate information on the ultimate use of engineered nanomaterials must be known for LCA. Key questions are as follows:

- Will the material be bound into matrices?
- Is the resulting product a liquid, powder, or solid?
- How is the product used? Is dispersion likely? How might the material degrade?
- Are the potential exposure routes intended or unintended?

Determine the stages in a product's life cycle that introduce the greatest potential for risk. Exposures to specific engineered nanomaterials may vary considerably based on the stage in the product's life cycle, which may impact the level of risk associated with a particular stage.

Develop environmentally benign manufacturing processes that can reduce the potential impact of nanomaterials. Research into processes and methods that utilize nontoxic, non-hazardous raw materials and that result in more resource-efficient techniques is needed to avoid negative impacts from nanomaterials on human health and the environment.

Understand the flow of nanomaterials through the economy and ultimate disposition. This MFA analysis will enable systematic identification of potential emissions and strategies for avoiding emissions, as well as likely exposure pathways.

Possible Research Approaches

Current efforts by Federal agencies and other groups attempting to apply LCA techniques to engineered nanoscale materials should be reviewed, and research into improving LCA techniques should be considered. Because of the high costs of LCA methodologies, LCA experts,

nanomaterial manufacturers, policymakers, scientists, and engineers must work collaboratively to ensure that the quantity and quality of data collected is appropriate.

The existing broad database for bulk compounds (the U.S. Life Cycle Inventory database at the National Renewable Energy Laboratory (see www.nrel.gov/lci/) initially could be used as a source of data on raw material-manufacturing processes and potential associated emissions. Collaborative efforts between industry and academia, where process and product-development data is shared with researchers in the LCA community, could supply data requirements for an inventory of nanomaterials in production. As the inventory of specific nanomaterials grows, more extensive or focused databases may be required.

Early comparative research on the effects of conventional versus engineered nanoscale material compounds during different stages in their life cycles will be very useful to LCA. LCA, in turn, will help to identify areas where nanomaterials might be able to reduce environmental impacts resulting from the use of other materials. The vast literature on particulate matter research could be especially informative here (see www.al.noaa.gov/AQRS/reports/srppm.html).

RISK COMMUNICATION METHODS

A critical element of effective risk management is communicating to potentially affected individuals a clear and relevant understanding of potential exposures and risks and, when faced with these uncertainties, to help those individuals make choices to reduce or avoid risk. Depending on the scenario, these potentially affected individuals may be, for example, workers, consumers, or residents who live in the vicinity of a factory. Risk communication models could be based on existing models for chemical (and pharmaceutical) incidents.

Risk communications with regard to existing nanomaterials must address workers in manufacturing and research facilities. Communications must include information on hazards and potential for exposure, as well as methods for managing risks. Although information gaps exist for nanomaterials, risk communications often involve probabilistic statements of risk for materials about which there is limited information. Further, management guidance also must be given even when incomplete information is available. Many technologies and products—for example, propane, household cleaning supplies, and electricity—have associated risks that are successfully managed by users.

Selected Relevant Federal Government Actions

- Federal agencies, including CPSC, FDA, EPA, and NIOSH, have notification mechanisms for communicating potential risks. An important part of CPSC's mission, for instance, is to inform the public about potential hazards from consumer products. The agency uses a variety of mechanisms to accomplish this, including local and national media coverage, publication of numerous booklets and product alerts, a website, a telephone hotline, the National Injury Information Clearinghouse, and CPSC's Public Information Center. The CPSC website also includes an interactive feature that allows consumers to report unsafe products and related injuries electronically. CPSC also maintains an email address (info@cpsc.gov) that can be used for inquiries about product recalls or to report potential product hazards.

For occupational settings, NIOSH can inform workers, employers, and safety and health professionals about newly identified occupational hazards through NIOSH Alerts (www.cdc.gov/niosh/alerts2.html).

- As noted earlier in this chapter, NIOSH has developed the document *Approaches to Safe Nanotechnology: An Information Exchange with NIOSH* to address worker information needs and to raise awareness of potential safety and health concerns from nanomaterial exposures.

6. Risk Management Methods

The document addresses current and future research needs essential to the understanding of potential risks nanomaterials may pose to workers. It is currently being used internationally to inform workers of related hazards (see www.cdc.gov/niosh/topics/nanotech/safenano/).

- FDA and CPSC have posted information on their regulatory approaches to products containing nanomaterials (see www.nano.gov/html/society/EHS.htm).
- NIOSH, in addition to the guidance document *Approaches to Safe Nanotechnology: An Information Exchange with NIOSH*, mentioned above, has created *NIOSH, Nanotechnology and Occupational Safety and Health Research—Frequently Asked Questions*, which is also available on its website (see www.cdc.gov/niosh/topics/nanotech/faq.html).
- NIOSH's National Occupational Research Agenda (NORA) held 12 meetings nationwide in 2005 and 2006 on research needs related to occupational safety and health. Inputs from those meetings will be considered by NIOSH in forming and revising research and risk communications practices for nanomaterials (www.cdc.gov/niosh/nora/).
- The NNCO has a document on its website titled *Reporting Risk Assessment of Nanotechnology* to help reporters with media analyses of risk-related research (www.nano.gov/html/news/reporting_risk_assessment_of_nanotechnology.pdf). The NNCO, in conjunction with DOE, also held a media roundtable in Berkeley, CA, in March 2006 with risk assessment included as a key part of the agenda.
- The NNCO held a workshop, Public Participation in Nanotechnology, in May 2006 to explore methods for public engagement on nanotechnology-related issues. Information gathered at this workshop will be used to assess risk communication needs and future public engagement activities.

Research/Information Needs

Evaluate whether current risk communications are adequate for known risks and for risks that can be anticipated from currently available information. Federal agencies will identify approaches to applying existing methodologies for informing the public about product hazards and potential product safety issues surrounding the use of nanomaterials in consumer products.

Where necessary, develop effective methods to communicate risk or safety information to potentially affected populations. If, in addition to workers, potentially affected populations are identified, communication strategies should be evaluated to ensure that risk communications are effective.

Possible Research Approaches

Existing methods to collect and disseminate information about exposure-related data from nanomaterial production facilities and downstream users could be evaluated. If beneficial, information could be conveyed through appropriate risk communication research methodologies for new engineered nanoscale materials.

It is important for Federal agencies to inform the public of risk situations. The currently existing mechanisms for reporting product problems and/or defects are also likely to be the most widely used for nanomaterial-related products. In addition, new mechanisms that provide reliable information on claims about engineered nanomaterials might be required.

GLOSSARY

ADME	Absorption, distribution, metabolism, elimination; ADME/Tox: Absorption, distribution, metabolism, elimination, and toxicity
ANSI (TAG)	American National Standards Institute (Technical Advisory Group)
CDC	Centers for Disease Control and Prevention
CFR	Code of Federal Regulations
CPSC	Consumer Product Safety Commission
CSREES	Cooperative State Research, Education, and Extension Service (USDA)
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOS	Department of State
DOT	Department of Transportation
EHS	Environmental, health, and safety
EPA	Environmental Protection Agency
FDA	Food and Drug Administration (HHS)
HHS	Department of Health and Human Services
HMR	Hazardous Materials Regulations
LCA	Life cycle assessment
NCI	National Cancer Institute (NIH/HHS)
NCL	Nanotechnology Characterization Lab (NCI/NIH/HHS)
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NEHI	Nanotechnology Environmental and Health Implications Working Group of the NSET Subcommittee
NIEHS	National Institute of Environmental Health Sciences (NIH/HHS)
NIH	National Institutes of Health (HHS)
NIOSH	National Institute for Occupational Safety and Health (CDC/HHS)
NIST	National Institute of Standards and Technology (DOC)
NNCO	National Nanotechnology Coordination Office
NNI	National Nanotechnology Initiative
NNIN	National Nanotechnology Infrastructure Network (NSF)
NRC	Nuclear Regulatory Commission
NSET	Nanoscale Science, Engineering, and Technology Subcommittee of the NSTC
NSF	National Science Foundation
NSRC	Nanoscale Science Research Centers (DOE)

Glossary

NSTC	National Science and Technology Council
NTP	National Toxicology Program (HHS)
OECD	Organisation for Economic Co-operation and Development
OSHA	Occupational Safety and Health Administration
PPE	Personal Protective Equipment
STAR	Nanotechnology Science to Achieve Results (EPA)
USDA	United States Department of Agriculture
USGS	United States Geological Survey (Department of Interior)
WATERS	Watershed Assessment, Tracking & Environmental Results (EPA program)

REFERENCES

- G. V. Andrievsky, V. K. Klochkov, E. L. Karyakina and N. O. Mchedlov-Petrosyan, Studies of aqueous colloidal solutions of fullerene C-60 by electron microscopy, *Chem Phys. Lett.*, 300, 392-396 (1999).
- G. V. Andrievsky, V. K. Klochkov, A. B. Bordyuh, and G. I. Dovbeshko, Comparative analysis of two aqueous-colloidal solutions of C60 fullerene with help of FTIR reflectance and UV-Vis spectroscopy, *Chem. Phys. Lett.*, 364, 8-17 (2002).
- American Institute of Chemical Engineers (AIChE), An example of existing guidelines is the Guidelines for Safe Storage and Handling of Highly Toxic Hazard Materials, American Institute of Chemical Engineer's Center for Chemical Process Safety (1988).
- American National Standards Institute Nanotechnology Standards Panel, *ANSI-NSP priority recommendations related to nanotechnology standardization needs*, NSP SC 027-2004, American National Standards Institute, Washington, DC. public.ansi.org/ansionline/Documents/Standards%20Activities/ANSI-NSP/ANSI-NSP%20SC%2027-2004%20Recommendations.pdf (2004).
- B. Ballou, B. C. Lagerholm, L. A. Ernst, M. P. Bruchez, A. S. Waggoner, Noninvasive imaging of quantum dots in mice, *Bioconjugate Chem.* 15(1), 79–86 (2004).
- C. Bennat, C. C. Müller-Goymann, Skin penetration and stabilization of formulations containing microfine titanium dioxide as physical UV filter, *Int. J. Cosmetic Sci.* 22(4), 271–283 (2000).
- J. Brant, H. Lecoanet, M. Hotze, M. Wiesner, Comparison of electrokinetic properties of colloidal fullerenes ($n\text{-C}_{60}$) formed using two procedures, *Environ. Sci. Technol.* 39(17), 6343–6351 (2005).
- Y. Cui, Q. Q. Wei, H. K. Park, C. M. Lieber, Nanowire nanosensors for highly sensitive and selective detection of biological and chemical species, *Science* 293(5533), 1289–1292 (2001).
- A. M. Derfus, W. C. W. Chan, S. N. Bhatia, Probing the cytotoxicity of semiconductor quantum dots, *Nano Lett.* 4(1), 11–18 (2004).
- D. W. Elliott, W. X. Zhang, Field assessment of nanoscale biometallic particles for groundwater treatment, *Environ. Sci. Technol.* 35(24), 4922–4926 (2001).
- European Commission Scientific Community on Emerging and Newly Identified Health Risks (EC-SCENIHR), *Opinion on the appropriateness of existing methodologies to assess the potential risks associated with engineered and adventitious products of nanotechnologies*, Brussels: European Commission. files.nanobio-raise.org/Downloads/scenihr.pdf (2005).
- European Commission Community Health and Consumer Protection, *Nanotechnologies: A Preliminary Risk Analysis on the Basis of a Workshop Organized in Brussels on 1–2 March 2004 by the Health and Consumer Protection Directorate General of the European Commission*. ec.europa.eu/health/ph_risk/documents/ev_20040301_en.pdf (2004).
- P. D. Gardner, K. C. Hofacre, A. W. Richardson, Comparison of simulated respirator fit factors using aerosol and vapor challenges, *J. Occ. Environ. Hyg.* 1(1), 29–38 (2004).
- N. V. Gopee, D. W. Roberts, P. Webb, C. Cozart, P. Siitonen, A. R. Warbritton, N. J. Walker, W. W. Yu, V. L. Colvin, P. C. Howard, Penetration of nanoscale quantum dots in dermabrased mouse skin. Abstract B-38, 2006 FDA Science Forum, Washington DC, 2006. Abstract available at www.cfsan.fda.gov/cgi-bin/abs-all.d.cgi?STYPE=2006&AUTHOR=quantum+dots (2006).
- J. J. Granier, K. B. Plantier, M. L. Pantoya, The role of the Al_2O_3 passivation shell surrounding nano-Al particles in the combustion synthesis of NiAl, *J. Mater. Sci.* 39(36), 6421–6431 (2004).

References

- J. J. Granier, M. L. Pantoya, The effect of size distribution on burn rate in nanocomposite thermites: a probability density function study, *Combust. Theory Modeling* **8**(3), 555–565 (2004).
- J. J. Granier, M. L. Pantoya, Laser ignition of nanocomposite thermites, *Comb. Flame* **138**(4), 373–383 (2004).
- M. Heim, B. J. Mullins, M. Wild, J. Meyer, G. Kasper, Filtration efficiency of aerosol particles below 20 nanometers, *Aerosol Sci. Technol.* **39**(8), 782–789 (2005).
- S. M. Hussain, K. Hess, J. M. Gearhart, K. T. Geiss, J. J. Schlager, *In vitro* toxicity of nanoparticles in BRL 3A rat liver cells, *Toxicol. In Vitro* **19**(7), 975–983 (2005).
- Institute of Occupational Medicine, *Nanoparticles: An Occupational Hygiene Review*. www.hse.gov.uk/research/rpdf/r274.pdf (2004).
- International Commission of Radiologic Protection, Deposition in the respiratory tract, In *ICRP Supporting Guidance 3: Guide for the Practical Application of the ICRP Human Respiratory Tract Model*, International Commission of Radiologic Protection series, first edition (2003).
- Joint Chemical Industry Consultative Board for Advancing Nanotechnology (NNI-ChI CBAN) and Semiconductor Research Council Consultative Working Group # 5 SRC NNI (CWG5), *Nanotechnology Research Needs Recommendations*, Semiconductor Research Council, www.src.org/member/news/snb_12_06_05.asp (2006).
- S. Kim, Y. T. Lim, E. G. Soltész, A. M. De Grand, J. Lee, A. Nakayama, J. A. Parker, T. Mihaljevic, R. G. Laurence, D. M. Dor, L. H. Cohn, M. G. Bawendi, J. V. Frangioni, Near-infrared fluorescent type II quantum dots for sentinel lymph node mapping, *Nature Biotechnol.* **22**, 93–97 (2004).
- H. F. Lecoanet, J. Y. Bottero, M. R. Wiesner, Laboratory assessment of the mobility of nanomaterials in porous media, *Environ. Sci. Technol.* **38**(19), 5164–5169 (2004).
- H. F. Lecoanet, M. R. Wiesner, Velocity effects on fullerene and oxide nanoparticle deposition in porous media, *Environ. Sci. Technol.* **38**(16), 4377–4382 (2004).
- K. W. Lee, B. Y. H. Liu, Experimental study of aerosol filtration by fibrous filters, *Aerosol Sci. Technol.* **1**(1), 35–46 (1982).
- P. R. Lockman, J. M. Kozlari, R. J. Mumper, D. D. Allen, Nanoparticle surface charges alter blood-brain barrier integrity and permeability, *J. Drug Target.* **12**(9-10), 635–641 (2004).
- R. Mach, *Nanoscale Particle Treatment of Groundwater*, Federal remediation technologies roundtable: Naval Facilities Engineering Command (2004), available at www.ftrr.gov/pdf/meetings/1--mach_09jun04.pdf.
- A. Magrez, S. Kasas, V. Salicio, N. Pasquier, J. W. Seo, M. Celio, S. Catsicas, B. Schwaller, L. Forro L. Cellular toxicity of carbon-based nanomaterials, *Nano Lett.* **6**(6), 1121–1125 (2006).
- D. Mark, T. Brown, D. Morgan, J. Lead and R. Harrison, A. Tye, S. Chenery, *Scoping Study to Identify Exposure Data Needs for Addressing the Risks Presented by Nanoparticles and Nanotubes*, DEFRA Research Project Report (2005), available at www.defra.gov.uk/environment/nanotech/research/reports/index.htm.
- A. D. Maynard, P. A. Baron, M. Foley, A. A. Shvedova, E. R. Kisin, V. Castranova, Exposure to carbon nanotube material: Aerosol release during the handling of unrefined single-walled carbon nanotube material, *J. Toxicol. Environ. Health A* **67**(1), 87–107 (2004).
- K. Morgan, Development of a Preliminary Framework for Informing the Risk Analysis and Risk Management of Nanoparticles, *Risk Analysis* **25**(6) (2005).
- NanoSafe, *Safe Production and Use of Nanomaterials*, www.nanosafe.org/node/277 (2004).

References

- National Research Council (NRC), *Risk Assessment in the Federal Government: Managing the Process*, Washington, DC: National Academy (1983).
- A. P. Nemmar, P. H. Hoet, B. Vanquickenborne, D. Dinsdale, M. Thomeer, M. F. Hoylaerts, H. Vanbilloen, L. Mortelmans, B. Nemery, Passage of inhaled particles into the blood circulation in humans, *Circulation* **105**(4), 411–414 (2002).
- NIOSH, *Approaches to Safe Nanotechnology: An Information Exchange with NIOSH*. www.cdc.gov/niosh/topics/nanotech/safenano/ (2005).
- NIOSH, *Evaluation of health hazard and recommendations for occupational exposure to titanium dioxide*, NIOSH Current Intelligence Bulletin Draft document for public comment, NIOSH Docket #33. www.cdc.gov/niosh/review/public/tio2/ (2005).
- NIOSH, *NIOSH respirator selection logic*, Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2005-100. www.cdc.gov/niosh/docs/2005-100/ (2004).
- NIOSH, *Strategic Plan for NIOSH Nanotechnology Research: Filling the Knowledge Gaps*. www.cdc.gov/niosh/strat_plan.html (2005).
- G. Oberdörster, A. Maynard, K. Donaldson, V. Castronova et al., Principles for Characterizing the Potential Human Health Effects from Exposure to Nanomaterials: Elements of a Screening Strategy, Report from the International Life Sciences Institute Research Foundation/Risk Science Institute Nanomaterial Toxicity Screening Working Group, *Particle and Fibre Toxicology*. www.particleandfibretoxicology.com/content/pdf/1743-8977-2-8.pdf (2005a).
- G. Oberdörster, E. Oberdörster, J. Oberdörster, Nanotoxicology: An emerging discipline evolving from studies of ultrafine particles, *Environ. Health Persp.* **113**(7), 823–839 (2005b).
- G. Oberdörster, Z. Sharp, V. Atudorei, A. Elder, R. Gelein, W. Kreyling, C. Cox, Translocation of inhaled ultrafine particles to the brain, *Inhalation Toxicol.* **16**(6-7), 437–445 (2004).
- G. Oberdörster, J. Ferin, B. E. Lehnert, Correlation between particle-size, *in-vivo* particle persistence, and lung injury, *Environ Health Perspect.* **102**(S5), 173–179 (1994).
- G. Oberdörster, J. Ferin, R. Gelein, S. C. Soderholm, J. Finkelstein, Role of the alveolar macrophage in lung injury—studies with ultrafine particles, *Environ. Health Perspect.* **97**, 193–199 (1992).
- Presidential/Congressional Commission on Risk Assessment and Risk Management, *Risk Assessment and Risk Management in Regulatory Decision-Making*, www.riskworld.com/Nreports/1997/risk-rpt/volume2/pdf/V2EPA.pdf (1997).
- D. Y. H. Pui, S. C. Kim, Penetration of Nanoparticles through Respirator Filter Media, *Final Report NIOSH Contract No. 254-2005-M-11698* (2006).
- D. W. Roberts, N. V. Gopee, B. J. Miller, D. Norton, A. R. Warbritton, J. R. Bucher, W. Yu, C. Sayes, V. L. Colvin, P. C. Howard, Localization of intradermally injected nanoparticle quantum dots in regional lymph nodes, *The Toxicologist*. **89**, 2185 (2005).
- D. W. Roberts, N. V. Gopee, A. R. Warbritton, N. J. Walker, W. W. Yu, V. L. Colvin, P. C. Howard, Polymer standards for quantitation of quantum dot tissue fluorescence, *The Toxicologist*. **90**, 829 (2006).
- The Royal Society and the Royal Academy of Engineering (RS,RAEng), *Nanoscience and nanotechnologies: opportunities and uncertainties*. www.nanotec.org.uk/finalReport.htm (2004).

References

- J. P. Ryman-Rasmussen, J. E. Riviere, N. A. Monteiro-Riviere, Penetration of intact skin by quantum dots with diverse physicochemical properties, *Toxicol. Sci.* **91**(1), 159–165 (2006).
- G. A. Stevens, E. S. Moyer, “Worst case” aerosol testing parameters: I. Sodium-chloride and dioctyl phthalate aerosol filter efficiency as a function of particle-size and flow-rate, *Amer. Indus. Hygiene Assoc. J.* **50**(5), 257–264 (1989).
- Swiss Re, Nanotechnology: *Small Matter, Many Unknowns*.
[www.swissre.com/INTERNET/pwswilpr.nsf/vwFilebyIDKEYLU/ULUR-5YNGET/\\$FILE/Publ04_Nanotech_en.pdf](http://www.swissre.com/INTERNET/pwswilpr.nsf/vwFilebyIDKEYLU/ULUR-5YNGET/$FILE/Publ04_Nanotech_en.pdf) (2004).
- K. Thomas, P. Sayre, Research strategies for safety evaluation of nanomaterials, part I: Evaluating the human health implications of exposure to nanoscale materials, *Toxicol. Sci.* **87**(2), 316–321 (2005).
- T. Thomas, K. Thomas, N. Sadrieh, N. Savage, P. Adair, R. Bronaugh, Research strategies for safe evaluation of nanomaterials, part VII: evaluating consumer exposure to nanoscale materials, *Toxicol. Sci.* **91**(1), 14–19 (2006).
- C. L. Tran, K. Donaldson, V. Stones, T. Fernandez, A. Ford, N. Christofi, J.G. Ayres, M. Steiner, J.F. Hurley, R.J. Aitken, A. Seaton, *A Scoping Study to Identify Hazard Data Needs for Addressing the Risks Presented by Nanoparticles and Nanotubes*, IOM Research Report (2005), available from www.defra.gov.uk/environment/nanotech/research/pdf/hazarddata-scoping.pdf.
- C. L. Tran, D. Buchanan, R. T. Cullen, A. Searl, A. D. Jones, K. Donaldson, Inhalation of poorly soluble particles. II. Influence of particle surface area on inflammation and clearance, *Inhal. Toxicol.*, **12**(12), 1113–1126 (2000).
- J. S. Tsuji, A. D. Maynard, P. C. Howard, J. T. James, C. W. Lam, D. B. Warheit, A. B. Santamaria, Research strategies for safety evaluation of nanomaterials, part IV: Risk assessment of nanoparticles, *Toxicol. Sci.* **89**(1), 42–50 (2006).
- U.S. Environmental Protection Agency (U.S. EPA), *Air Quality Criteria for Particulate Matter, Volume II*, EPA/600/P-99/002bF (2004).
- U.S. Environmental Protection Agency (U.S. EPA), *An examination of EPA risk assessment principles & practices*, EPA Staff Paper. www.epa.gov/osa/pdfs/ratf-final.pdf (2004).
- U.S. Environmental Protection Agency (U.S. EPA), Guidelines for Exposure Assessment. Risk Assessment Forum, Washington, DC, 600Z-92/001.
cfpub.epa.gov/ncea/raf/recordisplay.cfm?deid=15263 (1992).
- U.S. Environmental Protection Agency (U.S. EPA), Nanotechnology Working Group, *Nanotechnology White Paper*, External Draft for Review. www.epa.gov/osa/nanotech.htm. (2005).
- U.S. Environmental Protection Agency (U.S. EPA), Office of Water, Office of Science and Technology, Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000): Technical Support Document Volume 2: Development of National Bioaccumulation Factors, www.epa.gov/waterscience/criteria/humanhealth/method/tsdvol2.pdf (2003).
- U.S. Environmental Protection Agency (U.S. EPA), *Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure*, EPA/600/R-06/063 (2006).
- D. W. VanOsdell, B. Y. H. Liu, K. L. Rubow, D. Y. H. Pui, Experimental-study of submicrometer and ultrafine particle penetration and pressure-drop for high-efficiency filters, *Aerosol Sci. Technol.* **12**(4), 911–925 (1990).
- Z. L. Wang, Nanostructures of zinc oxide, *Materials Today*, **7**(6), 26–33 (June 2004).

References

- D. B. Warheit, T. R. Webb, C. M. Sayes, V. L. Colvin, K. L. Reed, Pulmonary instillation studies with nanoscale TiO₂ rods and dots in rats: Toxicity is not dependent upon particle size and surface area, *Toxicol. Sci.* **91**(1), 227–236 (2006).
- H. Yamawaki, N. Iway, Cytotoxicity of water-soluble fullerene in vascular endothelial cells, *Am.J.Physiol.Cell.Physiol.*, **290**(6), C1495–1502, ajpcell.physiology.org/cgi/content/abstract/290/6/C1495 (2006).
- W. Zhang, Nanoscale iron particles for environmental remediation: An overview, *Journal of Nanoparticle Research* **5**(3), 323–332 (2003).

*National Science and Technology Council
Committee on Technology
Subcommittee on Nanoscale Science, Engineering, and Technology*

*National Nanotechnology Coordination Office
4201 Wilson Blvd.
Stafford II, Rm. 405
Arlington, VA 22230*

*703-292-8626 phone
703-292-9312 fax*

www.nano.gov

