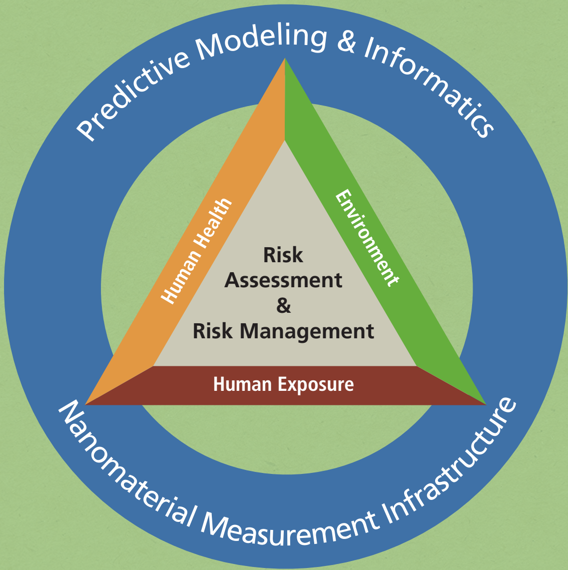
Key Concepts in the 2011 National Nanotechnology Initiative

Environmental, Health, and Safety Research Strategy



Terminology in the NNI Environmental, Health, and Safety Research Strategy

Consistent with the 2006 report *Environmental, Health, and Safety Research Needs for Nanomaterials*, and for the purposes of this document, the term *engineered nanomaterials** refers to those materials that have been purposely synthesized or manufactured to have at least one external dimension of approximately 1–100 nanometers (nm)—at the nanoscale—and that exhibit unique properties determined by this size. In this document, when the term *nanomaterials* is used alone, it refers to engineered nanomaterials.

This definition also applies to *nanotechnology-enabled products*, that is, intermediate engineered nanoscale products, including nanomaterials embedded in a matrix material, that exist during manufacture and in final products.

NanoEHS is used in this strategy document as a shorthand term to refer to nanotechnology-related environmental, health, and safety (research, etc.).

* The term *engineered nanomaterials* is applicable to the NNI 2011 EHS Research Strategy and overall nanotechnology-related EHS research. This term does not necessarily apply to Federal regulatory statutes or policies relevant to nanotechnology.

On the cover: The six core research areas in the NNI EHS Research Strategy—Nanomaterial Measurement Infrastructure, Human Exposure, Human Health, Environment, Risk Assessment & Risk Management, and Informatics & Modeling—are strongly interrelated and synergistic, as illustrated in the cover logo. The risk of nanomaterials to both humans and the environment is the product of both exposure and hazard. Thus, science-based risk assessment and risk management require data that address research needs in human exposure, human health, and the environment. The generation and organization of a vast body of *accurate and reproducible* data requires both a comprehensive set of nanomaterial measurement tools and predictive modeling and informatics capabilities. The NNI EHS Research Strategy requires progress in all six research areas at the same time in order to be successfully implemented.

Introduction

Nanotechnology is a young field of science and engineering that is already providing solutions and products that benefit the public. The National Nanotechnology Initiative (NNI) was established in 2000 as the Federal Government's nanotechnology research and development program and provides a mechanism for agency cooperation to achieve shared goals and strategies. To maximize benefits and minimize potential risks from nanotechnology, the NNI agencies have developed a research strategy specifically focused on environmental, health, and safety (EHS) aspects of the field. Such a strategy can guide Federal agencies as they establish their own nanotechnology research programs.

To develop the 2011 NNI EHS Research Strategy, the NNI agencies evaluated the 2008 NNI EHS Research Strategy and research developments over the last three years. This assessment included collecting and analyzing new information from the NNI agencies responsible for overseeing the manufacture and use of engineered nanomaterials and nanotechnology-enabled products. Similarly, a wide array of stakeholders—advisors to the government, academia, industry, non-governmental and public health advocacy organizations, and the general public—gave their input to the strategy. Development of the 2011 NNI EHS Research Strategy and integration of stakeholder comments was managed by the Nanotechnology Environmental and Health Implications Working Group of the interagency Nanoscale Science, Engineering, and Technology Subcommittee of the National Science and Technology Council's Committee on Technology.

This brochure summarizes key concepts in the 2011 NNI EHS Research Strategy and the steps being taken to understand and minimize potential harm of nanotechnology to humans and to the environment. The complete strategy, as well as several background reports, are available at **Nano.gov** and on the attached CD.

NNI EHS Mission

The NNI agencies serve the public good through the development and implementation of a coordinated nanotechnology environmental, health, and safety research strategy that

- Protects public health and the environment
- Employs science-based risk analysis and risk management
- Fosters technological advancements that benefit society.

Table of Contents

The following pages describe several key concepts that the NNI agencies used to develop the EHS research framework, the major components of the strategy, and key steps to implement the strategy.

Framing the 2011 NNI EHS Research Strategy:

Risk Assessment

The NNI agencies responsible for oversight of nanotechnology EHS research drew upon and adapted as necessary several traditional concepts and analysis tools used in safety research. One process used to assess the safety of new materials and chemicals is called *risk assessment*. The steps in risk assessment are:

Hazard Identification. What is the potential of a material to be hazardous to human health and/or to the environment?

Exposure Assessment. What is the size of an exposure that could occur and what is the possibility that people and/or the environment will be exposed?

Dose-Response Relationship (People) or Dose and Effect (Environment). What is the amount and the form of a nanomaterial that causes an adverse effect? This is referred to as a dose-response relationship when discussing people and is called an assessment of dose and effect for the environment.

Risk Characterization. This step integrates the data from the previous steps into an overall assessment of risk.

Risk assessment is an approach that scientists and Federal agencies often use to identify nanomaterials with the highest potential for exposure and/or hazard, and to focus early research on those materials.

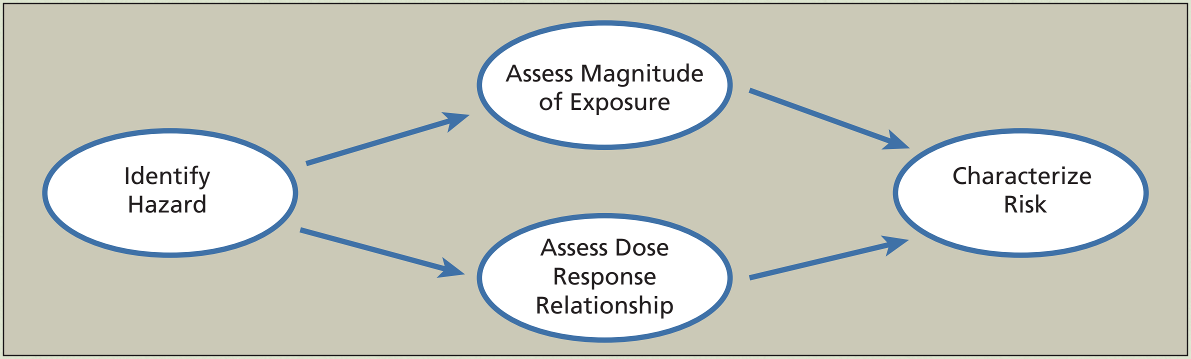


Figure 1. Risk assessment process. Risk is often defined as a mathematical equation Risk = Hazard times Exposure or R = H x E. This means that the size of the risk is equal to the size of the hazard measurement made for a material multiplied by the size of the exposure. Source: US EPA.

Risk is a Function of Both the Hazard and the Exposure

(a) High Hazard, High Exposure (b) High Hazard, Low Exposure (c) Low Hazard, High Exposure

Figure 2. Examples of Exposure and Risk Scenarios. In this series of examples, the shark represents hazard and the human, exposure. (a) There is a high degree of hazard and exposure that translates into high risk. (b) The cage protecting the human in (b) decreases direct exposure, although the hazard from the shark remains high. (c) The small sharks in (c) are less hazardous, although the exposure remains high.

N.R. Fuller of Sayo-Art provided graphics. Images used by permission: (a) Surfer image—SXC.hu, http://www.sxc.hu/photo/1160675; Shark image—Eli Snyder, http://www.freenaturepictures.com/shark-mouth-1.php. (b) Diver—Jim O'Dell, SXC.hu, http://www.sxc.hu/photo/1295077; Shark: SXC.hu, http://www.sxc.hu/photo/830948. (c) Ken Colwell, http://www.flickr.com/photos/kcolwell/5173128811/.

Framing the 2011 NNI EHS Research Strategy:

Product Life Cycle Stages

The product life cycle assessment presents additional opportunities to identify and reduce potential adverse impacts of nanotechnology. The product life cycle describes all of the stages in making, using, and disposing of a product: from extracting raw materials to research and development to product design and manufacture to commercialization to consumer use to disposal or recycling of the product at the end of its life (Figure 3). This concept, in combination with risk assessment, provides scientists with information to identify potential points of exposure and environmental impact at each stage of the product life cycle. Its use in developing a research framework allows researchers and Federal agencies to focus research efforts on the stages at which the largest and most hazardous exposures might occur and to provide more timely data for risk characterization and risk management. Overall, life cycle assessment supports sound product development, responsible nanomanufacturing practices, and protection of public health and the environment.

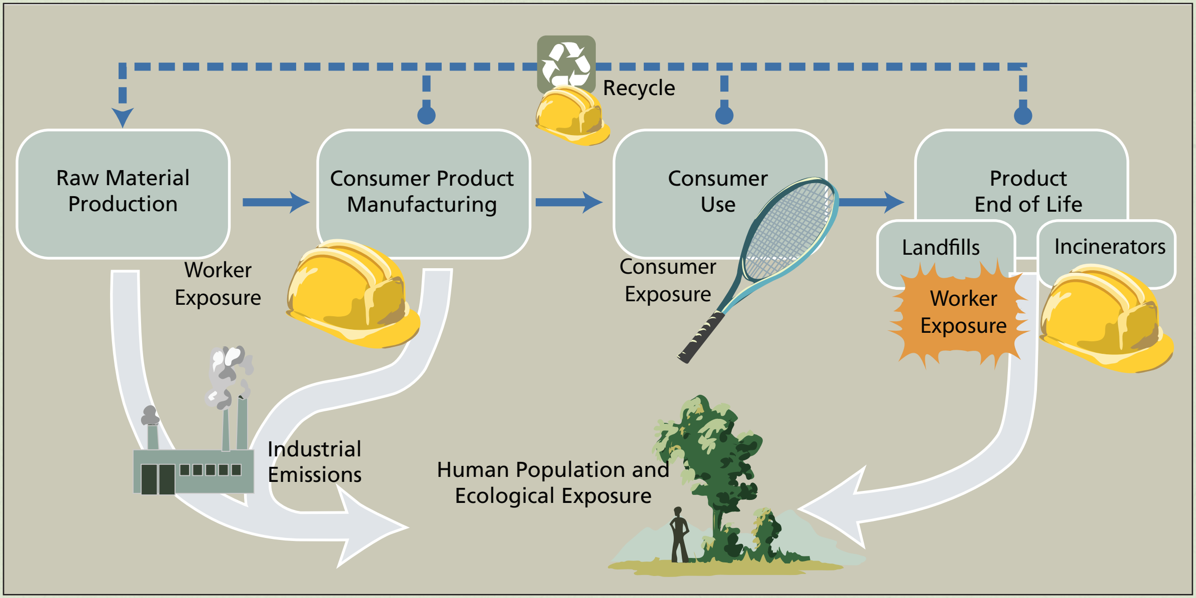


Figure 3. The life cycle perspective on risk assessment. Life cycle assessment is a comprehensive way to evaluate a nanomaterial and/or nanotechnology-enabled product at each step of product development, use, and disposal. This approach allows scientists, industry, and interested stakeholders to identify when a worker might be exposed to a nanomaterial (shown here as yellow hard hats), where industrial emissions should be evaluated (lower left figure), and where in the life cycle consumers and the general public might experience an exposure.

Source: EPA 100/B07/001, February 2007, http://epa.gov/osa. N.R. Fuller of Sayo-Art provided revised image graphics.

Integrating the Key Concepts of Risk Assessment and Product Life Cycle

These concepts—risk assessment and product life cycle stages—guided the development of the research framework underpinning the NNI EHS Research Strategy. When integrated, as in Figure 4, specific research themes and target areas are identified. For example, nanomaterials released into the environment may be changed by environmental conditions such as temperature and the salt content of water. Environmental conditions such as the surrounding soil, water, animals, and foliage may alter the form of nanomaterials to which people and the environment are exposed. These changes may make the nanomaterials more or less hazardous and can occur at any point along the product life cycle.

The concentration of nanomaterials in the environment will depend on factors such as the type and amount of the nanomaterial released, its physical and chemical properties, and time. As depicted in blue and red in this continuum (Figure 4), nanomaterials released into the environment may undergo transformation by environmental conditions. In turn, the transformed nanomaterials may modify atmospheric, soil, or water chemistry. These transformations may alter the form of the nanomaterials that are transported through the environment and the nanomaterials to which people and the environment are exposed. Biological or environmental systems may be exposed to these nanomaterials and respond through systems and pathways designed to buffer exposures to substances that could change a human health condition or adversely impact the environment.

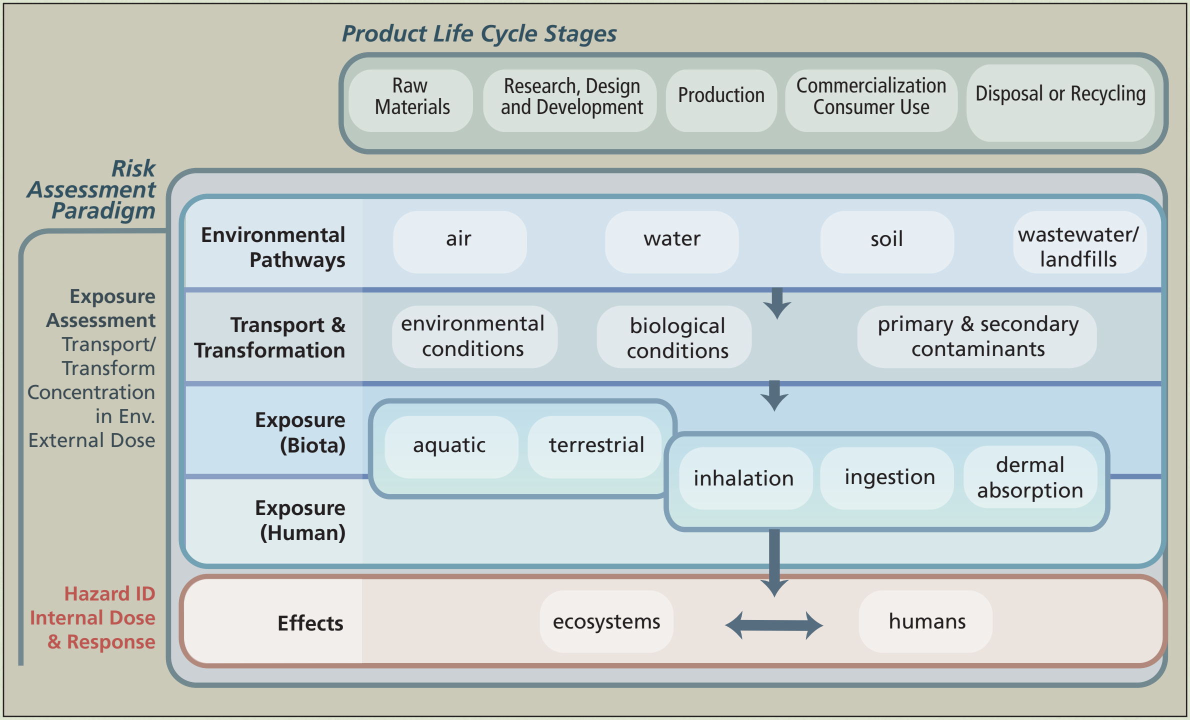


Figure 4. The risk assessment paradigm combined with nanomaterial life cycle stages incorporates the key risk assessment components—exposure assessment, hazard identification, and dose–response (left-hand column)—with nanomaterial life cycle stages—from raw materials through commercialization and end of product life (across the top) and the environmental exposure–effects pathways.

Source: NEHI and N.R. Fuller of Sayo-Art.

NNI Risk Management Research Framework

The NNI EHS Research Strategy is organized to achieve two goals: to protect public health and the environment and to support development of nanotechnology products to solve critical issues for society. No technology has ever been without some risk, including nanotechnology. Therefore, the NNI EHS research framework focuses on the goal of risk management (Figure 5), a concept that, for the purposes of the strategy, encompasses the product life cycle, regulatory decision-making, public outreach, and research planning.

Drawing on the integration of risk assessment and product life cycle (Figure 4), the framework identifies the core research areas that provide the scientific information on (1) measurement of nanomaterials, (2) human exposure assessment, (3) human health assessment, and (4) environmental effects assessment. Data from these categories are integrated and used in the core research area (5) risk assessment and risk management methods. Informatics (6) is included because it is essential for managing data and developing theories, models, and simulations of a material's behavior.

Ethical, legal, and societal implications (ELSI) of nanotechnology encircle these research components to highlight the need for inclusion of these broader considerations in the design of research in all six of the research categories (Figure 5). The commitment to ELSI considerations helps Federal agencies focus on public trust by considering

- How nanotechnology research and applications are introduced into society
- How transparent decisions are
- How sensitive and responsive policies are to the needs and perceptions of stakeholders.

The dynamic nature of this EHS Research Strategy is captured in Figure 5 by feedback loops that show how new data affects both the research process and risk management decisions.

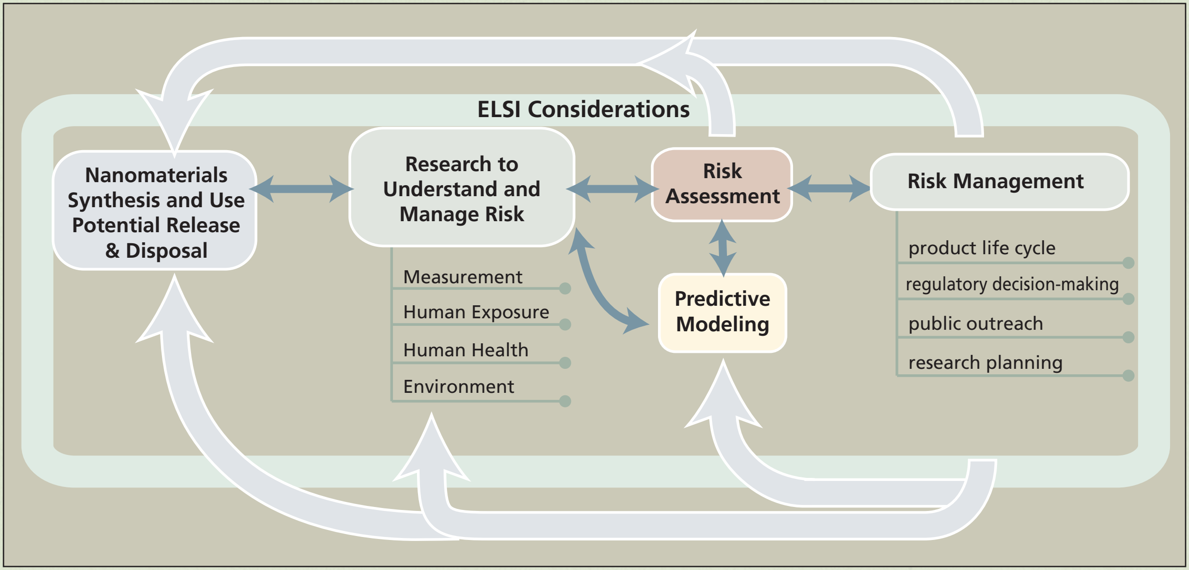


Figure 5. Risk management research framework for nanotechnology-related risk management, regulatory decision-making, product use, research planning, and public outreach.

Source: NEHI and N.R. Fuller of Sayo-Art.

Core Research Area:

Nanomaterial Measurement Infrastructure

Experiments to test the effect of a nanomaterial exposure on humans and the environment require scientists to know as precisely as possible the amount of nanomaterial that caused a response. Therefore, it is necessary to identify, modify, or develop the measurement tools to quantify and characterize nanomaterials along the product life cycle and in biological systems. More precise instruments will produce more accurate and reproducible results, and better risk assessment and risk management.

Tools are needed that are capable of

- More precisely measuring the physical and chemical characteristics of nanomaterials
- Detecting and monitoring potential hazards under realistic exposure conditions,
- Determining how nanomaterials change during their life cycle
- Measuring and evaluating the biological effects of nanomaterials and nanotechnology-enabled products (NEPs)
- Evaluating how nanomaterials and NEPs are released from complex materials and products.

Example of Progress in Nanomaterial Measurement

A critical first measurement for all nanotechnology environmental, health, and safety (nanoEHS) research studies is nanomaterial size, because size affects physical, chemical, and biological properties and, thus, exposure hazards. NanoEHS research has suffered from a lack of reliable nanoscale measurement standards that will give consistent data from one lab to the next and that will show that the performance of measurement instruments and analytic techniques is also the same from lab to lab.

In January 2008, the National Institute of Standards and Technology issued its first reference materials (RMs) for nanomaterials targeted for the nanoEHS and biomedical research communities—literally "gold standards" for determining the size of nanoparticles (Figure 5). The new reference materials, gold spheres nominally 10 nanometers (nm), 30 nm, and 60 nm in diameter, were measured using six independent methods commonly used by researchers in order to demonstrate the accuracy of their size.

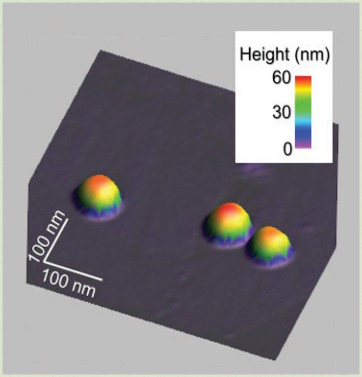


Figure 6. (Left) NIST gold nanoparticle reference materials (RMs) 8011–8013. (Right) Atomic force microscopy image of 30 nm gold reference material nanoparticles.

Source: **http://www.nist.gov/srm/index.cfm**. Image: J. Grobelny

Core Research Area:

Human Exposure Assessment

The number of products already in use or under development that contain nanomaterials has grown rapidly. They include plastics, metals, ceramics, creams, sprays, cosmetics, electronics, clothing, drugs, medical devices, and medical imaging aids. Exposure potential for nanomaterials is dependent on manufacturing methods, the nanomaterial state and its physical and chemical properties, and the nanomaterial applications. Hence, research must evaluate to what degree exposure may occur for each nanomaterial at each stage of its life cycle. Where nanomaterials are embedded in the product itself, such as in computer circuit boards, exposure during routine use is unlikely because the embedded nanomaterials are not on the surface. However, exposure of workers during manufacturing, including activities like grinding, must still be considered. Further exposure can occur to workers and consumers during misuse and during recycling or disposal at the end of product life. To protect workers and responsibly move nanotechnology forward, research needs include

- Conducting foundational toxicology research
- Measuring nanomaterials in workplace air
- Measuring exposure potential of consumers when using products containing nanomaterials
- Evaluating approaches to control exposure, including personal protective equipment.

Example of Progress in Human Exposure Assessment

The National Institute of Occupational Safety and Health (NIOSH) measures exposures in the workplace and performs laboratory research on exposure materials to understand the biological consequence of the exposure. Findings from field investigations and laboratory research on nanomaterials are integrated into the NIOSH guidance, *Approaches to Safe Nanotechnology: Managing the Health and Safety Concerns Associated with Engineered Nanomaterials* (http://www.cdc.gov/niosh/docs/2009-125/).

This guidance

- Identifies nanotechnology occupational safety and health issues
- Makes recommendations on occupational safety and health best practices in the production and use of nanomaterials
- Facilitates communications between NIOSH, industry, labor, and academia
- Responds to requests for authoritative safety and health guidelines
- Identifies information gaps and areas for further study.

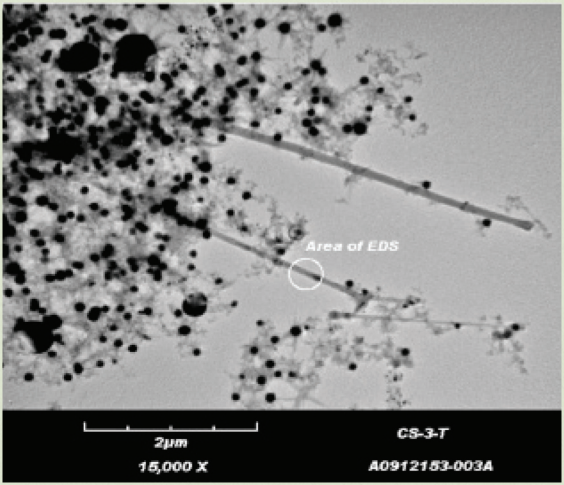


Figure 7. (Left) A researcher harvests single-walled carbon nanotubes from a carbon arc reactor. (Right) An air sample that was collected from the researcher's personal breathing zone (PBZ) while harvesting carbon nanotubes. The image was generated by transmission electron microscopy (TEM) with energy dispersive spectroscopy (EDS).

Source: National Institute for Occupational Safety and Health.

Core Research Area:
Human Health

As nanomaterials are used in more and more commercial products and processes, the potential for human exposure increases, and it becomes very important to understand how the human body responds to nanomaterials. The human health research need examines how nanomaterials are taken up by and distributed around the body, how they cause a biological response, and how they are retained by or excreted from the body.

Scientists use multiple, established model systems to perform this research, including models of healthy, vulnerable, and susceptible populations. Vulnerable and susceptible populations may respond to a nanomaterial exposure differently than healthy individuals, and these populations include, for example, children, the elderly, and those with pre-existing disease. With results from other core research areas, human health research results will provide the information necessary for risk assessors and managers to understand and develop guidance on the potential human health risk of exposure to nanomaterials.

Human health research needs include

- Developing reliable and reproducible bioassays and model systems to understand the human response to nanomaterial exposures
- Quantifying and characterizing nanomaterials in real-world exposures and biological conditions
- Understanding the relationship between the physical and chemical properties of nanomaterials and their transport, distribution, change, and excretion from or retention within the human body
- Examining how the human biological response to nanomaterials occurs at the molecular, cellular, tissue, organ, and whole body level
- Determining the extent to which life stages and susceptibility factors modulate potential health effects associated with exposure to nanomaterials.

Example of Progress in Human Health Research

Early concern about the safety of nanomaterials arose because of the use of nanomaterials in skin products. Nanoscale titanium dioxide and zinc oxide, through their ability to act as sun block agents in sunscreens, can reduce skin cancer from cell damage caused by the sun. But there was concern about the ability of nanomaterials to penetrate the skin and enter the body. To answer this question, several Federal agencies conducted research that examined both acute and chronic exposure of skin to sunscreen formulations. They determined that healthy, intact skin provides a barrier to entry of nanomaterials in sunscreens.

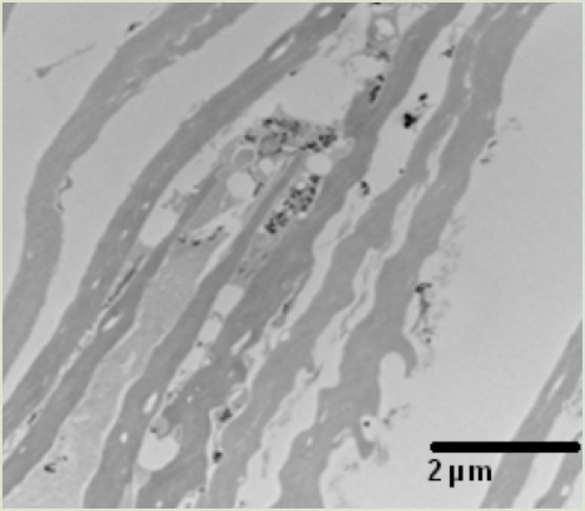


Figure 8. Electron microscope image of titanium dioxide nanoparticles in the top layer of the skin following administration of nanoscale titanium dioxide. No significant skin penetration of nanoscale titanium dioxide from sunscreen formulations was observed.

Source: N. Sadrieh, A. M. Wokovich, N.V. Gopee, J. Zhen, D. Haines, et al., Lack of significant dermal penetration of titanium dioxide (TiO_2) from sunscreen formulations containing nano- and submicron-size TiO_2 particles. *Toxicological Sciences* 115, 156-166, 2010.

Core Research Area:

Environment

The core EHS research category on the environment describes research to understand and control potentially harmful effects of nanomaterials on ecological receptors such as fish and birds, and on the ecosystems that they occupy. Releases of nanomaterials can occur at any stage of the product life cycle. The physical and chemical properties of nanomaterials at the time of release, and the change, or transformation, of the nanomaterial by the immediate environment, influence how the nanomaterial may move, deposit, build up, and transform in the environment. These processes may make the nanomaterial less or more hazardous than its original form.

Research produced by environmental scientists is also important to other core research areas. Information on transport and transformation is critical to understanding the types of exposures that should be measured, where they should be measured, and which human, animal, and plant populations might be exposed. Thus, research to understand the environmental impact of nanomaterials is necessary for good risk management.

Research needs for environmental studies include

- Identifying the principal sources of environmental exposure and the mechanisms through which exposures might occur
- Determining the factors affecting the environmental transport of nanomaterials
- Examining the transformation of nanomaterials
- Understanding the effects of nanomaterials on specific individuals in a type of plants or animals and how well scientists are able to measure these effects
- Evaluating the effects of nanomaterials on populations, communities, and ecosystems.

Example of Progress in Environmental Research

Case studies are helping to refine research on nanomaterials that can reduce the risk of unintended consequences. One example: in August 2010, the U.S. Environmental Protection Agency released a case study, Nanoscale Silver in Disinfectant Spray. It includes an environmental assessment framework that integrates a product life cycle perspective with the risk assessment paradigm and addresses environmental fate and transport, exposure-dose, ecological and human health, and other potential impacts of nanoscale silver in a spray product. This case study describes what is known about silver nanoparticles in one application to help identify and prioritize data gathering that will support long-term assessment efforts. The study notes that the behavior of nanomaterials is greatly influenced by the properties of the particles and the composition and chemistry of the surrounding environment. This influence may also extend to the toxicity of nanoparticles. Some evidence exists that particle size and surface properties affect the toxicity of silver nanoparticles.

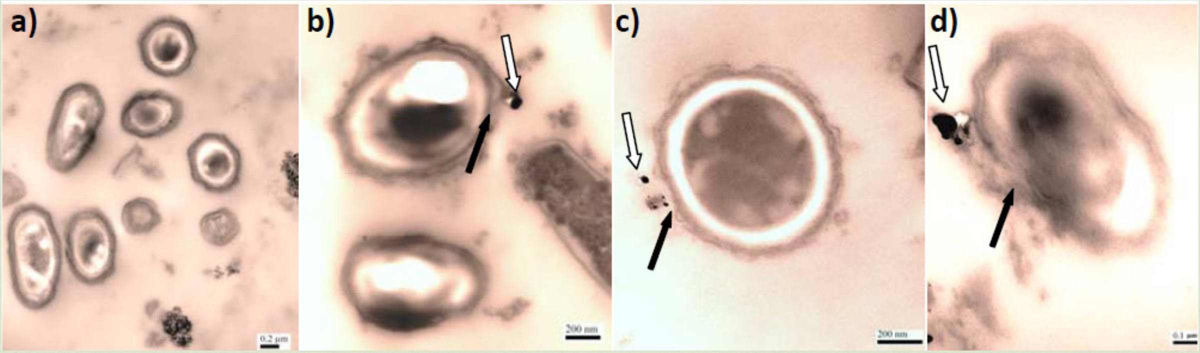


Figure 9. Transmission electron micrograph images of cells exposed to silver nanoparticles: (a) unexposed cells, (b–d) cells exposed to silver nanoparticles that vary from highly negative surface charge to highly positive. White arrows indicate silver nanoparticles (b–d); black arrows (b–d) indicate damage to cell membranes The positively charged silver nanoparticles exhibited the highest toxicity and caused bacterial death at all investigated concentrations, whereas the most negatively charged particles exhibited the least toxicity.

Source: U.S. EPA

Core Research Area:

Risk Assessment and Risk Management Methods

The core research areas of nanomaterial measurement, exposure assessment, human health, and environment provide the data necessary for risk assessment and risk management. The process of risk assessment applies analytical data tools and expert knowledge to evaluate hazard and potential exposure of humans and the environment to nanomaterials and to determine the effects that might be associated with exposure. Risk management methods identify and implement strategies to address these potential hazards. Risk management employs scientific information and expert judgment to compare the risk for different nanomaterials; integrate life cycle evaluations; and consider ethical, legal, and societal implications (ELSI) of nanotechnology, including stakeholders' values and additional information needs.

Risk research plays an important role in understanding these different kinds of data and integrating them into an effective risk management strategy. Risk assessment and risk management research needs include

- Incorporating hazard identification, exposure and effect assessment, and risk characterization into the safety evaluation of nanomaterials
- Understanding, characterizing, and controlling workplace exposures to nanomaterials
- Integrating life cycle considerations into risk assessment and risk management
- Integrating risk assessment and decision analysis into risk management
- Integrating and standardizing risk communication to stakeholders within the risk management framework.

Example of Progress in Risk Assessment and Risk Management Methods

Nanoscale titanium dioxide, when exposed to ultraviolet light, can kill harmful microorganisms such as bacteria. Because of this property, it is widely used in products to clean and disinfect glass. A special laboratory has been developed with a controlled clean environment and instruments to measure the release of nanomaterials from these cleaning products. In this room, experiments can be done to gather risk characterization information on consumer products and produce exposure data that can be used to evaluate health risks. This method is publicly available to guide industry and consumer groups in the development and evaluation of spray products that may contain nanomaterials.

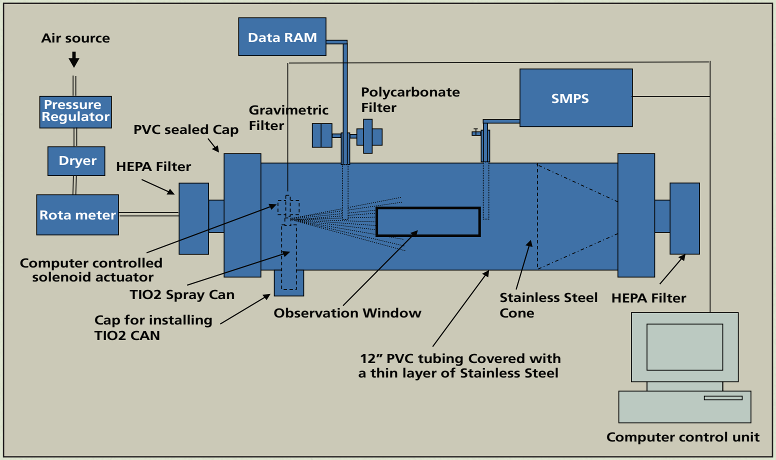


Figure 10. (Left) Nanoparticles-containing spray can aerosol; (Right) Characterization, exposure assessment, and generator design.

Source: B.T. Chen, A. Afshari, S. Stone, M. Jackson, D. Schwegler-Berry, D.G. Frazer, V. Castranova, T.A. Thomas, Nanoparticles-containing, spray can aerosol: Characterization, exposure assessment, and generator design, *Inhal. Toxicol.* 22, 1072-1082, 2010.

Core Research Area:

Informatics and Predictive Modeling for NanoEHS Research

As progress in nanotechnology EHS research is made, the need to organize large amounts of data in a systematic way has become increasingly important. Drawing on expertise in the field of informatics, the NNI agencies recognize the need to develop an interagency computational structure to house nanoEHS data. An expanded informatics capability would allow scientists to store, share, and use data to advance more rapidly the understanding of nanomaterials safety.

Furthermore, scientists and engineers are able to manipulate the physical and chemical characteristics of nanomaterials very precisely to solve specific problems. This precision, linked to an understanding of which subset of physical and chemical properties cause nanomaterials to be safe or hazardous, suggests that maximum safety and minimal risk might be engineered into nanomaterials. To test this idea, researchers are exploring the development of computer models that might predict safety or risk for a given nanomaterial. Predictive modeling, coupled with informatics initiatives, would speed collaboration through a nanomaterials databank, pilot websites, and simulation applications and tools.

Research needs to achieve these informatics and modeling goals include

- Evaluating the ability of biological assays to produce reliable and reproducible data for computational models
- Designing and establishing structures for capturing, sharing, and analyzing data
- Evaluating and adapting existing computational models
- Sharing nanomaterial computational models through publicly accessible nanotechnology websites.

Example of Progress in Predictive Modeling

Begun in 2007, the Collaboratory for Structural Nanobiology is developing a database to construct, validate, and share molecular models of nanomaterials. One example of its work and the potential benefit of predictive modeling is the use of fullerenes, or a sixty carbon cage-like structure, in cancer therapy. Carbon fullerenes can bind up free hydrogen and oxygen atoms in cells, making fullerenes an ideal candidate to protect healthy cells during cancer x-ray treatment. To make fullerenes more effective at getting into cells, researchers added simple (DF1-mini) or complex branch-shaped (DF1) molecules to the surface (Figure 11). Scientists tried to predict which form would be most effective in protecting cells from x-rays using models. Two-dimensional models—the ball and stick drawings on the top of the figure—looked very similar. In contrast, new 3-dimensional models (bottom of figure) more accurately predicted that the smaller branches would stick out from the fullerene cage, whereas the complex branches would wrap around the cage and produce a safer cancer treatment.

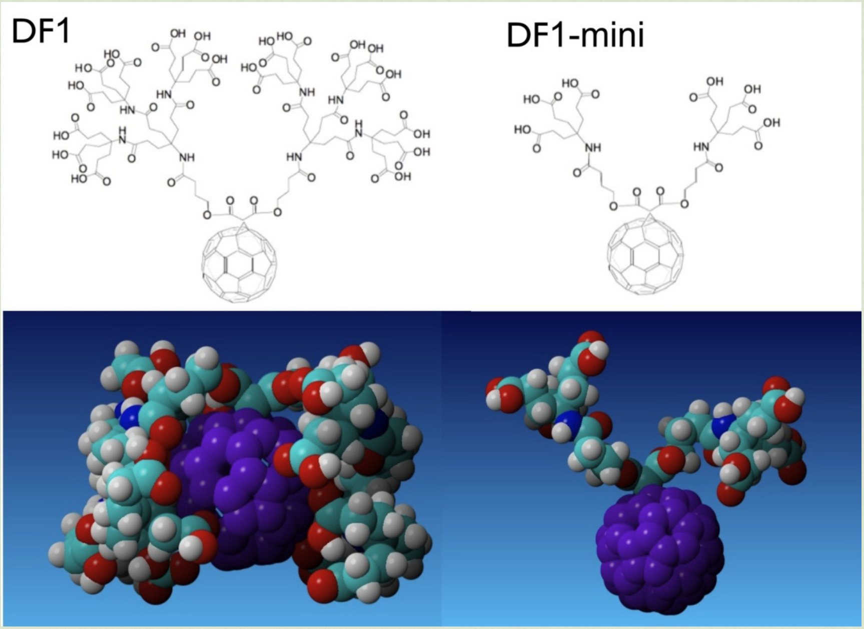


Figure 11. DF1 (left) vs. DF1-mini (right) structural models. Top: 2D rendition. Bottom: The most prevalent 3D conformations obtained during simulations.

The Path Forward

To realize the goals of the NNI EHS Research Strategy, NNI agencies will need to take advantage of collaboration among NNI agencies, academia, industry, non-governmental organizations (NGOs), the general public, and international bodies. The NNI is committed to an interagency EHS research strategy, with the NSET Subcommittee and its NEHI Working Group helping to facilitate nanoEHS research. The NEHI Working Group has identified the following principles to assist agencies in making strategic decisions about their nanoEHS research programs:

- Prioritize which nanomaterials to research
- Establish standard measurements, terminology, and nomenclature
- Maximize data quality
- Stratify knowledge for risk assessment
- Partner to achieve the NNI EHS research goals
- Engage internationally.

These principles will help the individual NNI agencies to target EHS research and accomplish their individual mandates. To identify plausible human and environmental risks associated with nanomaterials exposure, it is necessary to prioritize ENMs and NEPs for study: (1) those that may provide a major contribution to the research knowledge base, and (2) those that may pose a more immediate safety concern.

Confidence in research results on nanomaterials, essential to risk assessment, is achieved through standardized measurements. Such measurements ensure the accuracy and reproducibility of research results, and thus provide a trustworthy knowledge base for evaluating exposure and hazards. There is a need for standardized terminology across agencies to fully characterize ENMs.

The NNI agencies will leverage public-private partnerships with industries, nongovernmental organizations, and universities to develop the necessary data.

The societal challenges for which nanotechnology may provide solutions are global, and provide opportunities for international collaboration. Many countries are concerned about the potential hazards of exposure to nanomaterials and nanotechnology-enabled products for the environment and human health.

Implementation and Coordination of the 2011 NNI EHS Research Strategy

This strategy will guide programs and investment decisions by the individual agencies and coordination of interagency activities. It should be noted that the agencies have varied missions, and their individual priorities may differ from those outlined in this report. Thus, coordination is essential, and agencies will work through the NSET Subcommittee, its NEHI Working Group, and the NNCO Coordinator for EHS to ensure the integration of agency implementation plans.

As part of its 2011 revision of the NNI EHS Research Strategy, NNI proposes

- Continued engagement in traditional scientific forums
- Building on new media efforts to engage more stakeholders, for example, in developing prevention strategies good handling practices, and regulatory standards
- Expanding work in data storage and management
- Creating public engagement events to share information on safety research and efforts to maximize societal benefits from nanotechnology while minimizing risks.

Conclusion

The vision of the 2011 National Nanotechnology Initiative Environmental, Health, and Safety Research Strategy—a future in which nanotechnology provides maximum benefit to the environment and to human social and economic well-being—is a national priority worthy of intense and sustained Federal effort.

The NNI agencies have a proven track record of working together and will continue to refine mechanisms of collaboration. Stakeholders have an essential role to play as the researchers, workers, and consumers directly involved in the development, manufacture, use, and recycling of engineered nanomaterials and nanotechnology-enabled products. As we move forward to achieve the NNI EHS research goals, agencies, in partnership with stakeholders, accept this responsibility to develop engineered nanomaterials and nanotechnology-enabled products that maximize benefit and minimize risk to public health and to the environment.

The National Nanotechnology Initiative (NNI) is the U.S. Federal Government's interagency program for coordinating research and development and enhancing communication and collaborative activities in nanoscale science, engineering, and technology. The NNI's goals are (1) to advance a world-class nanotechnology R&D program; (2) to foster the transfer of new technologies into products for commercial and public benefit; (3) to develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; and (4) to support responsible development of nanotechnology.

The Nanoscale Science, Engineering, and Technology (NSET) Subcommittee in the interagency body responsible for coordinating, planning, implementing, and reviewing the NNI. It is a subcommittee of the National Science and Technology Council.

Under the auspices of the NSET Subcommittee, the Nanotechnology Environmental and Health Implications Working Group coordinates the NNI's environmental, health, and safety research efforts.

NNI Agencies

Office of Science and Technology Policy (OSTP)

Office of Management and Budget (OMB)

Bureau of Industry and Security (BIS/DOC)

*Consumer Product Safety Commission (CPSC)

*Department of Defense (DOD)

Department of Education (DOEd)

*Department of Energy (DOE)

Department of Homeland Security (DHS)

Department of Justice (DOJ)

Department of State (DOS)

Department of Transportation (DOT)

Department of the Treasury (DOTreas)

Director of National Intelligence (DNI)

*Environmental Protection Agency

*Food and Drug Administration/Department of Health & Human Services (FDA/DHHS)

*Forest Service /Department of Agriculture (FS/USDA)

National Aeronautics and Space Administration (NASA)

*National Institute of Environmental Health Sciences/ National Institutes of Health (NIEHS/NIH/DHHS)

*National Institute of Food and Agriculture/Department of Agriculture (NIFA/USDA)

*National Institute for Occupational Safety and Health/ Dept of Health & Human Services (NIOSH/DHHS)

*National Institute of Standards and Technology (NIST/ DOC)

*National Science Foundation

Nuclear Regulatory Commission

*Occupational Safety and Health Administration/ Department of Labor (OSHA/DOL)

*U.S. Geological Survey (USGS)

*U.S. International Trade Commission (USITC)

U.S. Patent and Trademark Office (USPTO/DOC)

*Also members of the NSET Subcommittee's Nanotechnology Environmental and Health Implications (NEHI) Working Group

Glossary of Acronyms

CPSC .... Consumer Product Safety Commission

C60 .... Carbon fullerenes

EHS .... Environmental, Health & Safety

ELSI .... Ethical, legal, and societal implications

ENM .... Engineered nanomaterials

FDA .... Food and Drug Administration

LCA .... Life cycle assessment

NCI .... National Cancer Institute (of NIH)

NEHI ....Nanotechnology Environmental and Health Implications Working Group

NIEHS .... National Institute of Environmental Health Sciences (of NIH)

NIH.. National Institutes of Health

NIOSH .... National Institute for Occupational Safety and Health

NIST ....National Institute of Standards and Technology

NNI..National Nanotechnology Initiative

NEP .... .Nanotechnology-enabled products

NSET .... Nanoscale Science, Engineering and Technology Subcommittee

NSTC ....National Science and Technology Council

OSTP ....White House Office of Science and Technology Policy

SRM... Standard reference materials

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Further Information: The attached CD has copies of the full 2011 NNI EHS Research Strategy and of reports from the four-part workshop series that informed the 2011 EHS Research Strategy. It also links to additional material on Nano.gov from those workshops, including webcasts and presentations. The CD has an auto-run file that should bring up a page of links to these resources when the CD is loaded on a PC. All material is also available at Nano.gov.

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