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RESEARCH AND DEVELOPMENT – OFFICE OF SCIENCE POLICY

The Technical Support Times is an online newsletter highlighting EPA field activities, research, and new documents on current topics. This issue is the sixth in a series of periodic publications from the Superfund & Technology Liaison (STL) Program of the Office of Science Policy (OSP) within the Office of Research and Development (ORD). All issues of the Technical Support Times are available on the Internet at http://www.epa.gov/osp/hstl/techsupp.htm/.

Michael Gill, STL for Region 9, and Charles Maurice, STL for Region 5, compiled this issue from various EPA resources.

FOCUS ON: NANOTECHNOLOGY

BACKGROUND

Nanotechnology involves the production, manipulation, or use of materials having at least one dimension 1 to 100 nanometers (nm) in length. A 1 nm length is equivalent to one billionth of a meter (10^{-9} m) or about 100,000 times smaller than the diameter of a human hair, 1,000 times smaller than a red blood cell, or about one-half the size of the diameter of DNA. Nano-sized materials or "nanomaterials" are used to create structures, devices, and systems that have novel properties and functions only possible because of their small size. The terms "nanomaterials" and "nanoparticles" generally refer to products intentionally manufactured via isolation (top down) or synthesis (bottom up). Thus, natural particles such as viruses and volcanic ash, or particles unintentionally generated such as ultrafine particulates from diesel exhaust, typically are not classified as nanoparticles, even though they may meet the size definition.

Nanotechnology presents potential opportunities to create better materials and products. Nanomaterial-containing products are available in U.S. markets, including coatings, computers, clothing, cosmetics,

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sports equipment, and medical devices. Nanotechnology also has the potential to improve the environment, both through direct applications of nanomaterials to detect, prevent, and remove pollutants, as well as indirectly by using nanotechnology to design cleaner industrial processes and create environmentally responsible products. Because of these potential benefits from nanotechnology, governments, industry, and academia around the world are paying close attention to developments in nanotechnology. The European Union and individual countries such as Japan, the Netherlands, England, China, Vietnam, Germany, Mexico, and Canada are making major investments in nanotechnology research and production. In the United States, the National Nanotechnology Initiative (NNI) was launched in 2001 to coordinate nanotechnology research and development (R&D) across the Federal Government. The NNI has 25 member federal agencies, including the U.S. Environmental Protection Agency (EPA). Since 2001, the NNI has coordinated an increase in federally funded nanotechnology-related activities from $464 million to approximately $1.4 billion in 2007. The proposed federal nanotechnology budget is $1.4 billion in 2008. EPA's request is $14.9 million for 2009. The NNI R&D agenda identifies fundamental nanoscale processes research, nanoparticle design, and nanotechnology-based devices and systems development as priorities.

Although nanotechnology applications offer promising benefits for many aspects of society, there are unanswered questions about the impacts of nanomaterials and nanoproducts on human health and the environment. EPA has an obligation to ensure that potential risks are adequately understood to protect human health and the environment. As a result, EPA has undertaken a variety of activities to improve our understanding of how nanomaterials might affect human health and the environment, including: the Science To Achieve Results (STAR) grants program, the EPA Nanotechnology White Paper, and a draft research strategy. In addition, the NNI, through its Nanotechnology Environmental and Health Implications (NEHI) Interagency Working Group, has been developing a list of research needs for environmental health and safety. Activities being conducted by the NNI can be explored further at http://www.nano.gov.

APPLICATIONS

At present, there are more than 500 commercially produced nanomaterial products and many more are under development. Correspondingly, because of the diversity of nanomaterial compositions, structures, sizes, and applications, there are many ways to categorize nanomaterials. One common nanomaterial categorization scheme is based on the following four broad categories: (1) carbon-based materials; (2) metal-based materials; (3) polymer-based materials or dendrimers; and (4) composites.

The broad range and versatility of nanotechnology provide the marketplace and society with many opportunities to produce and utilize new materials with novel properties and attributes. The National Science Foundation (NSF) projects that revenues from commercial nanotechnology applications will be about $1 trillion by the year 2015. The unusually large surface area to volume ratios and small size, as well as other nanometer scale-related unique features, give manufactured nanomaterials novel electrical, catalytic, magnetic, mechanical, thermal, hardness, and strength properties. These properties can be highly desirable for certain commercial, medical, and military applications. Just one such benefit from the reduced weight and increased strength of items made

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from nanomaterials could be increased fuel efficiency of vehicles. Sunscreens, cosmetics, cleaning products, composites, medical and electronic devices, chemotherapeutic agents, fuel additives, and chemical catalysts are just a few of the available nanotechnology products.

Nanotechnology also is beginning to be used in environmental applications to help clean up the environment, control pollution, and monitor environmental contaminants. Zero valent iron nanoparticles have been used to remove volatile organic compounds such as trichloroethylene (TCE) from soil and ground water. When added to diesel fuel, cerium oxide nanoparticles can decrease diesel emissions, and nano-enabled sensors can be used to improve detection and tracking of contaminants in the environment. For more details on some products that already exist, see the Woodrow Wilson International Center for Scholars' Consumer Products Inventory at http://www.nanotechproject.org/inventories/consumer. This list, started by the EPA Office of Research and Development's (ORD) Nora Savage, is not exhaustive but does show how pervasive nanomaterials are in society. ■

IMPLICATIONS

Although many nanomaterials may not lead to human health or ecological concern, a number of scientists agree that not enough information exists to understand exposure and effects of many manufactured nanomaterials now entering the marketplace. The EPA Nanotechnology White Paper cautions: "There is a significant gap in our knowledge of the environmental, health, and ecological implications associated with nanotechnology (Dreher, 2004; Swiss Report, 2004; UK Royal Society, 2004; European NanoSafe, 2004; UK Health and Safety Executive, 2004)."

Some of the same properties related to their extremely small size, which make nanomaterials so useful, also may impact human and environmental receptors. For example, some nanomaterials are able to pass through cell membranes or cross the blood-brain barrier. This membrane permeability attribute provides great promise for medical applications such as targeted drug delivery and other disease treatments. This same property, however, also may result in unintended consequences. If receptors are exposed to similar manufactured nanomaterials in an uncontrolled manner in the environment, potentially toxic substances may be able to circumvent biological barriers. Airborne nanoparticles could be inhaled and become lodged in the lungs, damaging lung tissue or perhaps worse, pass into the bloodstream where the nanoparticles could be carried throughout the body to any organ. Once in tissue, lung, or otherwise, the extraordinary reactivity of some nanomaterials may damage or disrupt cellular processes or even lyse the cells and kill them. Some studies have shown that certain types of synthetic nanoscale materials (fullerenes) have destroyed lipid cells in fish. These types of cells also are the most common form of brain tissue.

Because of the potential implications from the use of nanomaterials, ORD has been encouraging a life-cycle approach to understanding the implications. Exposure to consumers and the environment has been a focus of examining the implications. Even if consumer products hold nanomaterials in a matrix, which minimizes exposure to consumers and the environment, we also should pay attention to the toxicity of raw materials used in producing nanomaterials, the workers who are exposed during production of the raw nanomaterials and consumer products, industrial emissions, and end-of-life concerns. Also of potential concern is the introduction of nanomaterials into the environment through the waste streams of homes and industries, as well as directly into ground water at Superfund remediation sites. Nanomaterials from cosmetics, for example, may enter sewage treatment plants, which are not designed to remove nanomaterials from the waste stream, and will go untreated into the waterways. Emissions from industries will enter the air near facilities in much the same way as particulate matter. ■

NANOTECHNOLOGY AND EPA

By working together with other governments, agencies, academia, industry, and NGOs, EPA strives to promote the safe and prudent development of nanotechnology. The challenge for EPA is to provide environmental protection, while also allowing society to benefit from nanotechnology. The benefits nanotechnology can potentially provide (from greater sustainability through pollution prevention to contaminant cleanup and environmental detection and monitoring) must be balanced with the unknowns and uncertainties regarding the potential environmental risks. EPA has the responsibility and regulatory authority for identifying and minimizing any adverse impacts to humans or ecosystems from exposure to any compound, including nanomaterials.

Since 2004, ORD has held regular meetings with scientists and engineers from other EPA offices to coordinate what each office is doing in the field of nanotechnology. The "NanoMeeters" group was formed to share information on nanotechnology developments; to provide peer review of nanotechnology research proposals of the EPA STAR grants program; and to assist each other in the preparation of nanotechnology presentations and fact sheets. In association with the NanoMeeters, ORD also maintains an internal EPA nanotechnology database that serves as an Agency nanotechnology information repository.

In February 2007, EPA published the *Nanotechnology White Paper* (EPA 100/B-07/001, available at http://www.epa.gov/osa/nanotech.htm). The purpose of the *White Paper* was to: (1) inform EPA management of science issues and needs associated with nano-technology; (2) support related EPA program office needs; and (3) communicate these nanotechnology science issues to stakeholders and the public. The *White Paper* described the interest of EPA in nano-technology across its programs, the statutory mandates of the Agency, and risk assessment issues specific to nanotechnology across environmental media.

In September 2007, ORD distributed a draft Nanomaterials Research Strategy (NRS) for internal peer review. The purpose of the NRS was threefold: (1) to guide the ORD nanotechnology research program; (2) to build on research needs identified in the *Nano-technology White Paper* and by the NNI; and (3) to describe key research questions. Key science questions are identified in the context of four research themes. These themes are:

- Sources, fate, transport, and exposure
- Human health and ecological research to inform risk assessment and test methods
- Risk assessment methods and case studies
- Preventing and mitigating risks.

Additionally, one of the NRS appendices provides a side-by-side comparison of research needs, as identified in the *Nanotechnology White Paper*, with ORD Research Plans. The draft research strategy will be made available to the public in early 2008, in advance of a peer review of the strategy.

EPA is a part of the Organisation for Economic Co-operation and Development (OECD) effort to promote international cooperation in ensuring the responsible development of health and environmental safety procedures for the manufacture of nanomaterials. Under the auspices of the OECD Chemicals Committee, EPA is working with other governments and stakeholders on environmental health and safety research strategies; safety testing and test guidelines; voluntary schemes and regulatory programs; and risk assessments and exposure measurements for manufactured nanomaterials. EPA also is sponsoring testing of nanomaterials under OECD programs. For more information regarding OECD nanotechnology activities, see: http://www.oecd.org/department/0,2688,en_2649_37015404_1_1_1_1_1,00.html. ■

ORD STL INVOLVEMENT

The Superfund & Technology Liaison (STL) Program, which provides a two-way link between ORD and the regions, has been instrumental in technology transfer concerning nanotechnology applications and implications for site remediation. The STLs have accomplished this by providing individual technical support and by chairing conferences and conference sessions, as well as presenting papers and participating on discussion panels.

STL Charles Maurice co-chaired the *Nanotechnology for Site Remediation Workshop* with Region 5 nanotechnology expert Warren Layne. This 2-day EPA workshop was jointly sponsored by the ORD-Office of Science Policy (OSP) and Region 5-Superfund Division (SFD) and was held in Chicago in September 2006. Approximately 100 government, industry, and academic scientists and engineers attended from across the United States. The focus of the first day was on nanotechnology applications especially relevant to Superfund and Resource Conservation and Recovery Act (RCRA) hazardous waste site cleanups, whereas nanotechnology implications and lifecycle assessment were featured during the second day. There were some presentations on R&D being conducted on environmental applications of nanotechnology, but because it is a relatively new area of technology, the majority of the activity has been at the laboratory and pilot study phases. The first full-scale remedy for a Superfund site was selected by EPA Region 2 for the Naval Air Engineering Station at Lakehurst, New Jersey (NAES-Lakeshurst) in 2003, was designed and implemented, and is currently being monitored. Martha Otto, Office of Solid Waste & Emergency Response (OSWER), and Mary Logan of Region 5 Superfund, provided several hazardous waste site cleanup case studies. All of these case studies involved nano-scaled zero valent iron (NZVI), which currently is the most common nanomaterial used for waste site remediation. Others include chemically functionalized compounds or metal ion specific transparent ceramic-based nanoporous materials. In Region 10 at the Tuboscope Site on the north slope of Alaska, NZVI was tested to reduce trichloroethane (TCA) and diesel fuel concentrations in ground water. This is thought to be the first test of NZVI in cold weather conditions. In other EPA regions, the U.S. Navy is remediating various volatile organic compounds (VOCs) in ground water with NZVI at both the Naval Air Station (NAS) in Jacksonville, Florida, and NAES-Lakehurst. During a pilot test at Launch Complex 34 in Florida, the National Aeronautics and Space Administration (NASA) tested emulsified NZVI (EZVI) by injecting it into ground water to remediate dense non-aqueous phase liquids (DNAPL) primarily consisting of TCE. In early 2007 during a pilot study at the Nease Superfund site in Ohio, NZVI was injected into the ground water to test its effectiveness in remediating VOCs. The study includes smaller pre-pilot studies and an investigation of the ecological effects of the treatment method. Information on the pilot can be found at http://www.epa.gov/region5/sites/nease/. Other EPA Regions are using and/or considering the use of NZVI in site remediation. The Proceedings of the Nanotechnology for Site Remediation Workshop can be viewed or downloaded at http://www.epa.gov/OSP/hstl/Nanotech%20Proceedings.pdf.

Nano Zero Valent Iron in an emulsion (image courtesy of Jacqueline Quinn, NASA)

STLs also played important roles in the highly successful EPA Workshop on Nanotechnology for Site Remediation in October 2005, in Washington, DC. STLs Michael Gill, Terry Burton, and Jon Josephs were active members of the organizing committee. Their contributions included participating in organizing committee meetings, inviting speakers, recruiting exhibitors, giving presentations, and chairing plenary and/or breakout sessions.

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STLs Michael Gill and Jon Josephs presented a paper with Martha Otto at the November 2006 *EPA STAR Nanotech Applications and GRO Progress Review Workshop*. During this presentation, they outlined many EPA nanotechnology research needs to academic and other research scientists. They described needs pertinent to each of the EPA programs, but especially to the Superfund and RCRA programs. Research needs were described for contaminant and pollution detection and identification, remediation and treatment, fate and transport, and risk assessment.

During 2007, STLs Charles Maurice and Michael Gill and Region 5 nanotechnology expert Warren Layne collaborated with scientists from the Superfund Basic Research Program (SBRP) of the National Institutes of Health/National Institute of Environmental Health Sciences (NIEHS) to hold 10 (almost monthly) Web-based seminars on *Nanotechnology – Applications and Implications for Superfund*. The monthly sessions of the seminar series attracted several hundred scientists and engineers from around the world. Topics ranged from nanomaterial chemistry, fate and transport, and toxicology and ecotoxicology to remedial nanotechnologies and risk assessment. Gill and Maurice also collaborated with some of these same scientists, in addition to other EPA scientists, to hold a special nanotechnology session during the 2007 National Association of Remedial Project Managers (NARPM) meeting. Once again, a full range of nanotechnology topics relevant to Superfund were covered.

STL Charles Maurice and Warren Layne are co-chairing the *International Environmental Nanotechnology Conference – Applications & Implications*, scheduled for October 7-9, 2008, in Chicago. The conference planning committee has more than 40 scientists and engineers from 7 federal agencies and includes STLs Jon Josephs and Michael Gill. The conference Web site can be accessed at http://www.epa.gov/OSP/stlworkshops.htm.

ORD RESEARCH GRANTS

From 2001 to 2007, the ORD STAR grants program funded 86 research grants for more than $29 million to study environmental applications ($12 M) and implications ($17 M) of nanotechnology.

This research has addressed applications of nanotechnology to protect the environment, including the development of: (1) low-cost, rapid, and simplified methods of removing toxic contaminants from water; (2) new sensors that are more sensitive for measuring pollutants; (3) green manufacturing of nanomaterials; and (4) more efficient, selective catalysts.

STAR program projects also have focused on possible harmful effects or implications of engineered nanomaterials. The most recent research solicitations include partnerships with the National Science Foundation, the National Institute for Occupational Safety and Health, and the NIEHS. Research areas of interest include nanomaterial fate, release, and treatment; transport and transformation; bioavailability; human exposure; toxicology; and lifecycle assessment. Web links to the proceedings from two recent meetings on STAR grant nanotechnology research workshops are included on page 8.

Additionally, ORD has funded nanotechnology applications projects through its Small Business Innovation Research (SBIR) Program.

EPA REGULATORY ISSUES

EPA is able to draw on the R&D experiences of EPA scientists who have conducted research in areas related to nanotechnology, such as the toxicity of ultrafine particulate matter. Further, scientists throughout EPA already have started to gear up for nanotechnology applications and implications and have begun to gather current information and plan for research. Nanotechnology and nanomaterials will affect all EPA programs in some manner. Some of these cross-program nexuses are remediation and treatment, sensors, water resource protection, energy, more efficient and effective materials, and fuel additives.

EPA is applying existing regulatory programs to nanotechnology. EPA has received and reviewed a number of new chemical notices under the Toxic Substances Control Act (TSCA) for nanoscale materials. In July 2007, EPA's Office of Pollution Prevention and Toxics (OPPT) released for public comment a Concept Paper for the Nanoscale Materials Stewardship Program under TSCA and a TSCA Inventory Status of Nanoscale Substances – General Approach. Based on the information in those documents and public comments, EPA announced the design of the stewardship program in January 2008. The program is intended to gather existing data and information from manufacturers and processors of nanoscale materials, identify and encourage the use of risk management practices in developing and commercializing nanoscale materials, encourage the development of additional test data, and encourage responsible development. For more information regarding this proposed program, see http://www.epa.gov/oppt/nano/.

Regulatory programs are facing many difficult issues related to nanomaterials, including: identification of nanomaterials, determining if existing test guidelines can be used, and developing approaches to assessing human health effects and environmental effects. ORD is playing a central role in helping programs with these issues. ORD has established work groups composed of scientists across ORD laboratories and centers to review existing test guidelines to determine whether they apply to nanomaterials, if modifications are needed, and if new guidelines should be developed. In a related activity, ORD scientists and management are playing a major role in OECD work groups that are reviewing OECD test guidelines, establishing a database, tracking environmental health and safety research, and beginning the process of testing representative nanomaterials.

The EPA OSWER Technology Innovation and Field Services Division (TIFSD) is compiling a database containing information about hazardous waste sites for which nanotechnology remedies have been or are being implemented, tested, and/or considered for addressing site contamination. The TIFSD also is preparing a fact sheet on the use of nanotechnology for site remediation that will be useful for site project managers. More information on nanotechnology involvement of the TIFSD can be found at http://clu-in.org/nano. In addition, the Office of Pesticide Programs is receiving several inquiries from chemical companies on what data are needed to register pesticides containing nanomaterials.

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AVAILABLE RESOURCES

ONLINE LINKS

EPA Nanotechnology Research Page
http://es.epa.gov/ncer/nano/

EPA's clu-in.org nanotechnology "Issue Area" Web Page
(http://clu-in.org/nano)

EPA Nanotechnology Fact Sheet
http://es.epa.gov/ncer/nano/factsheet/
http://es.epa.gov/ncer/nano/factsheet/nanofactsheetjune07.pdf

National Nanotechnology Initiative
http://www.nano.gov/

EPA Nanotechnology Research Projects
http://es.epa.gov/ncer/nano/research/index.html

Woodrow Wilson International Center's Nanotechnology Products Inventory
http://www.nanotechproject.org/inventories/consumer

EPA NANOTECHNOLOGY CONFERENCES/WORKSHOPS

U.S. EPA Workshop on Nanotechnology for Site Remediation
Washington, DC: October 20-21, 2005
http://www.frtr.gov/nano/

Nanotechnology and OSWER: New Opportunities and Challenges
Washington, DC: July 2006
This symposium featured national and international experts, researchers, and industry leaders who discussed issues relevant to nanotechnology and waste management practices and focused on lifecycle assessment of nanotechnology.
http://esc.syrres.com/nanotech/agenda.html.

Nanotechnology for Site Remediation Workshop
Chicago, IL: September 6-7, 2006
This EPA workshop was jointly sponsored by Region 5 and ORD and focused on the use of nanotechnology for hazardous waste site remediation. ORD STL to Region 5 Chuck Maurice and Region 5 nanotechnology expert Warren Layne co-chaired the workshop. This 2-day workshop featured a day of presentations on nanotechnology remedial applications, including case studies, followed by a day of talks on the potential associated risks and implications. Almost 100 academic researchers, regulators, and business representatives participated.
http://www.epa.gov/OSP/hstl/Nanotech%20Proceedings.pdf

2006 EPA STAR Nanotechnology Environmental Applications and GRO Progress Review Workshop
Arlington, VA: November 8-9, 2006
http://www.scgcorp.com/nano-app-gro/index.asp

2006 EPA, NSF, and NIOSH STAR Nanotechnology Environmental Implications Workshop
Arlington, VA: November 13-14, 2006
http://www.scgcorp.com/Nano-Implication/index.asp

2007 EPA NARPM (National Association of Remedial Project Managers) Conference Nanotechnology Session: Solutions, Challenges, and Implications for Superfund
Baltimore, MD: May 21-25, 2007
http://www.ttemidev.com/narpm2007Admin/conference/materialsList.cfm?scheduleID=152

2007 EPA Pollution Prevention Through Nanotechnology Conference
Arlington, VA: September 25-26, 2007
A forum to exchange ideas and information on using nanotechnology to develop new ways to prevent pollution.
http://www.epa.gov/opptintr/nano/agenda.htm

Future EPA Nanotechnology Conferences/Workshops

International Conference on Environmental Nanotechnology – Applications & Implications
Chicago, IL: October 7-9, 2008
http://www.epa.gov/OSP/stlworkshops.htm