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Panel Discussion
A panel composed of the conference speakers and EPA personnel held a discussion during which they addressed the charged questions 1) Based on what is currently known in the nanotechnology area, what can be inferred about the properties and characteristics of a nanotechnology waste? and 2) How can nanotechnology impact current waste management practices for wastes?

Panel Members
Dr. Elizabeth Lee Hofmann, US EPA OSWER, Moderator

Mr. Jim Willis, US EPA OPPT

Dr. Barbara Karn, US EPA ORD, Woodrow Wilson International Center for Scholars/Emerging Nanotechnologies Project

Dr. Nora Savage, US EPA ORD, National Center for Environmental Research/Environmental Engineering Research Division

Ms. Marti Otto, US EPA OSRTI

Mr. Tracy D. Hester, Bracewell & Giuliani LLP, Houston TX

Mr. Mark Greenwood, Ropes & Gray, Washington DC

Dr. Stig Irving Olsen, Technical University of Denmark, Lyngby Denmark

Dr. Lou Theodore, Manhattan College, Department of Chemical Engineering

Mr. John Scalera, US EPA, Washington DC

Dr. Anil K. Patri, National Cancer Institute (SAIC Frederick) Frederick MD

Dr. Gregory V. Lowry, Carnegie Mellon University, Pittsburgh PA

Dr. David Warheit, E.I. DuPont de Nemours & Co., Inc Newark DE

Questions from OSWER to the Panel:

Based on what is currently known in the nanotechnology area, what can be inferred about the properties and characteristics of a nanotechnology waste?

Dr. Olsen: Nanotechnology is a horizontal technology, and will disperse into many types of products. Most waste streams will end up containing nanomaterials or nanotechnology products. One of the biggest issues is the depletion of scarce resources. We need to improve means of recovery of valuable materials from waste, possibly before it becomes waste.

Dr. Warheit: The issue of how to identify nanoparticles in waste is a very difficult problem. Even when we can control all of the variables in the lab, we can obtain different results depending on what we look for and what methods we use, even when working with the same material. Also, aggregation and agglomeration are issues when dealing with waste streams. We need to develop a life cycle assessment framework for product stewardship. DuPont, in collaboration with the Environmental Defense Fund, is attempting to do this. We should also carry out experimental simulations using one or two standardized materials, to determine which methods and which parameters to use (size, shape, charge, and surface characteristics).

Mr. Scalera: There are issues of complexity when dealing with environmental samples; some fundamental studies can be done before you reach that stage. We should start with fundamental studies to determine where to invest research funds (e.g., nanoparticles that are produced in significant volumes and are hazardous). First, we need to develop a feel for whether there is a hazard associated with the given nanoparticle. Then, you need to consider the production volume. If there is evidence of toxicity and large production volume, then you might want to consider its environmental fate and assess whether the nanomaterial is available in a toxic form and if other toxic forms are present. Instead of running a series of life cycle assessments (LCAs) to elucidate fate and transport, we may want to determine whether it aggregates in the environment. I am not aware of any standard methodologies to assess aggregation potential. Does the nanoparticle aggregate or agglomerate, and how easily? How toxic is the nanomaterial in each of its forms? Is there some way to disrupt the agglomeration? If it aggregates, can the aggregate be disrupted? There is a series of 4 to 5 more simplistic experiments that should be performed before LCA.

Dr. Patri: From the perspective of nanomaterial intended for medical application, this issue is difficult because of the diversity of materials involved, and the fact that most are in mixtures, are multifunctional, and/or are coated (to make them soluble or multifunctional with proteins attached, chemotherapeutics, heavy metals used for contrast agents, etc.). You generally may not see naked nanoparticles in the waste stream of nanomaterial.

Dr. Savage: Right now we test materials compound by compound, and we're only just beginning to understand/consider synergistic effects of compounds in the environment. OSWER should understand stability and degradation of nanomaterials, and waste products of nanomaterials (do they get caught by scrubbers, do they move in leachate, accumulate in sludge, are they subject to biological activation, inactivation, breakdown, etc.). It's important to know how nanomaterials could affect properties of leachate.

Mr. Willis: OSWER should consider whether it is possible to categorize nanomaterials or identify subsets of materials that are of greater or lesser concern (i.e., free nanoparticles, nanomaterials bound in a matrix, or one-dimensional nanomaterial coatings) as a way of setting priorities. OSWER should review the nanotechnology white paper, the ORD research framework, and the NNI research strategy to make sure that its needs get reflected in the research areas being considered.

Dr. Karn: The scientific literature may not contain reports of nanomaterials in which toxicity has not been observed, because negative results are not typically published. Scientists are expected to publish results; are researchers finding things to be toxic, just to get published? There is no journal of negative results; should there be a scientific journal or other mechanism devoted to negative findings (i.e., that a particular nanomaterial has no toxicity)?

Mr. Hester: While we may not have complete information about the properties of nanowastes, we need to understand which data will be important for decisions on whether and how to regulate nanoscale wastes. The ORD's strategy might serve as a mini-roadmap for research to identify these waste management regulatory issues. But more importantly, we should attempt to use an organized and cohesive approach to target the information that we need to handle discarded nanomaterials.

Dr. Lowry: The ongoing research to develop new nanoparticles makes it difficult to predict what the future will hold (i.e., what types of properties new nanomaterials may have). To date, colloid science explains the mobility of available nanomaterials; I've yet to come across a case where colloid science has not been able to explain nanoparticle mobility. There is a lot of research being done to develop new products with the expectation of revealing novel properties. It's not entirely clear yet where we need to apply more than standard colloid science to describe nanoparticle mobility.

Mr. Greenwood: Chemistry required for understanding nanowaste is typically not a part of traditional waste management. The chemistry required for understanding nanowaste is more than what is currently considered in waste stream considerations. We will need to know a lot more about what's in the waste stream, how it behaves in the environment, etc. We will need to reevaluate and revalidate our methods for waste treatment to see if they work with nanomaterials. We will need to consider how to control nanoparticles – does existing protective equipment work well enough? HEPA filters and new personal protective equipment (PPE) for handling nanowaste may need to be developed.

Mr. Hester: While we rightly have focused on some of the risk issues raised by nanomaterials, we shouldn't forget the beneficial pollution prevention aspects of nanotechnology. Nanotechnology has an enormous capacity to reduce the production of wastes in industrial processes, and it can remediate contamination and environmental releases in much more effective ways. For example, nanotechnology may allow for a new array of filtering technologies that could reduce wastes and/or the hazard posed by those wastes. Beyond these beneficial uses, we need to the time now to determine what uses of nanomaterials – including direct releases into the environment for remediation – might pose the vector of greatest impact. This assessment might include important data such as identifying the most likely sources of nanoscale wastes, or determining the impact of household wastes that will contain nanomaterials

A commenter asked, Do you know which waste streams will be producing the most nanomaterial waste?

Mr. Hester: No, although some consumer products containing nanomaterials have already entered the market and are undoubtedly being discarded. But for now, we don't know which products or waste streams will generate the largest volume of discarded nanomaterials.

Dr. Theodore: A bottom-up approach involves little to no waste. From an environmental management perspective, this is a big advantage. This would be a positive development from a pollution prevention standpoint. A more advanced approach to nanotechnology will involve improved environmental management practices.

Dr. Olsen: Hopefully future production techniques will reduce waste. Consumer waste will be one of biggest areas of nanowaste. A possible benefit of nanotechnology could be the use of radio frequent identification tags (RFID) to improve identification and recovery of different materials.

Dr. Karn: Nanosensors could be used to monitor nanomaterials in waste streams -- “nano measuring nano.”

Dr. Theodore: This can also enable us to measure terrorist threats.

Ms. Otto: We need to invest resources in evaluating and improving our measurement and monitoring techniques. An immediate concern is making sure that we’re monitoring fate and transport at field testing sites.

A questioner asked how we can use bottom-up techniques to assess effects (quantum mechanics as an example).

Dr. Karn: Green nanotechnology is emphasizing a consideration of bottom-up technologies (e.g., can we use self-assembly to reduce waste and improve the efficiency of production).

Mr. Willis: It might be beneficial to look at programs like the Resource Conservation Challenge: are there waste problems out there that nanotechnology can be used to solve? OSWER could look downstream at products or processes where “macro” chemicals are being replaced by nanoscale materials being replaced by nano-enabled products to get a sense of what is likely to enter the waste streams as well as the implications of dispersive use of nanoparticles. (e.g., release of nanoscale zero valent iron for site remediation). Engaging in the planned case study work can help here. Also, is there some way of making nanoparticles benign once the intended use ends?

Mr. Greenwood: We should be very open to the public with respect to how waste streams are managed. We need to consider what kind of information companies should be required to provide. Tort liability is a concern here; companies will want to avoid liability.

Dr. Warheit: OSWER needs to be very specific in what it wants to know, and how it formulates questions. Questions need to be clearly defined.

The discussion was opened to the audience.

A questioner asked whether ultrafine particles need to be regulated and whether nanoparticles that can penetrate biological membranes should be described as macromolecules.

Dr. Warheit: Not all nanoparticles and not all ultrafine particles behave the same. Nanoparticles have different biological activities. They may be able to translocate to different parts of the body. Also, nanoparticles could aggregate and become larger particles.

Dr. Lowry: Some nanoparticles do aggregate in the environment but it’s quite possible that in a biological system you have a small fraction of particles that remain unaggregated. Three- to 5-nm particles are not macromolecules. They are Rhinovirus-sized.

Dr. Patri: The size of C60 buckyballs is similar to that of small molecules. Depending on what is bound to the nanomaterial in the body, it may be larger. Smaller-sized nanomaterials can be characterized using the same methods used for small molecules.

Dr. Lowry: We will want to have classifications for the particles – we can't look at all possible individual chemicals. But we don't know what the classifications should be yet.

A questioner asked if there are any other ways to classify nanomaterials.

Mr. Scalera: We may need to experiment to identify nanoparticles of concern before generating fate studies and toxicity studies.

A commenter noted that we may want to conduct pharmacokinetics studies, starting with the most common nanoparticles. Maybe certain nanoparticles can be lumped with ultrafines for regulatory purposes.

The second question was posed to the Panel.

How can nanotechnology impact current waste management practices for wastes?

Dr. Lowry: The most near-term application is using nanomaterials that have reactive and physical properties that allow us to remediate things that we can't get to easily such as deep surface contamination. We know that we can utilize nanoparticles and get surface chemistries that did not previously exist. This can allow us to remediate recalcitrant chemicals (e.g., PCBs, dioxins, different radionuclides) and waste in hard-to-reach spaces.

Dr. Theodore: Nanoparticles have unique, novel properties that can be utilized for waste remediation (waste water, air pollutants, etc.). Adsorptive properties can clean up water and gas streams. In addition, they have catalytic properties and that too can lead to destruction of toxic gaseous materials. Since we have a near-infinite number of new chemicals at our disposal, we might look at this from a pollution prevention point of view: can we replace current chemicals with new nanomaterials that don't have toxicological issues?

A questioner asked whether there is a possibility that our current environmental management approach is not applicable to nanoparticles, because of the nature of these materials.

Dr. Theodore: Many traditional practices will still apply (e.g., recycling and waste reduction) but new practices will have to be developed. The traditional approaches (e.g., source management, control, P2 hierarchy) will generally apply. Not much will change in terms of control (e.g., disposal will still use landfills).

Mr. Scalera: In a waste stream, agglomeration may result, and regulating by mass (quantity) may no longer apply in instances where toxicity is reduced by agglomeration.

Also, bioavailability will need to be accounted for. We will need to determine what toxicity characteristics are important.

Dr. Karn: I agree that some management changes are needed. EPA could evolve into addressing three problem areas: 1) current -- what we do with current laws; 2) past -- what we could have done right, but we still have to fix; 3) future -- get ahead of the science and commercial aspects, and anticipate problems.

Mr. Greenwood: Nanotechnology is a good opportunity to look at the link between waste management and the time when a chemical comes into commerce. Management programs typically consider product development and waste separately. We need to align waste management and product programs and ask the right questions in the beginning.

A commenter noted that the Office of Water has developed a framework for identifying nanomaterials in pharmaceuticals and personal care products (including medical products). Wastewater streams will contain nanomaterials from such products.

Dr. Karn: The waste stream issues are important from the consumer disposal standpoint. Nanoscale drugs will enter wastewater after being excreted from the body. Also, disposal of unused drugs that have not been through the body (e.g., how do you dispose of old prescriptions?)

A questioner asked whether it is possible to engineer particles with a finite lifespan and/or activity (e.g., that only exist at a certain temperature or pressure).

Mr. Willis: There may be opportunities to design benign particles (hydroxylating buckyballs). It's not clear whether this changes performance of the nanoparticles.

Dr. Lowry: Certain polymers can be designed to breakdown; this may be useful. Krzysztof Matyjaszewskii at Carnegie Mellon University designs polymers with groups that hydrolyze at known rates that would then break up the polymer into biodegradable components and lose functionality. Polymer chemistry is probably leading to the ability to design particle coatings with finite lifetimes.

Dr. Patri: Dendrimers that hydrolyze to benign products are being produced. Once they deliver the drug, they can be destroyed, resulting in glycerol and lactic acid. However, this will not be possible with all types of nanomaterials.

Mr. Greenwood: We should steer clear of developing new stovepipe programs; rather, we should build capacity to consider nanotechnology issues in multiple existing programs. There needs to be coordination and communication between programs.

Dr. Patri: The common defining feature of these nanomaterials is size; however, we must standardize the characterization of nanosized particles. It is important to be able to compare particles from different laboratories. Otherwise, we are not sure we're talking about the same thing. NIST is developing standard reference materials (SRMs) that will be thoroughly characterized. The first SRM will be based on size, then we will develop other SRMs within that size range with additional characteristics. The NIST/NCL development and characteristics of these SRM will be made publicly available. Quantity is an issue—it is difficult to produce 0.5 grams of nanoparticles. Once there is a real commercial application, it is easy to scale up production.