Center for the Environmental Implications of NanoTechnology (CEINT) – Duke University

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The Center for the Environmental Implications of NanoTechnology is exploring the relationship between a vast array of nanomaterials—natural, manufactured, and those produced incidentally by human activities— and their potential consequences for the environment and organisms. The Center was created in 2008 with funding from NSF and the U.S. Environmental Protection Agency, and performs fundamental research on the behavior of nano-scale materials in laboratory and complex ecosystems. Research includes all aspects of nanomaterial transport, fate and exposure, as well as toxicity and ecosystem impacts, and the development of tools for risk assessment. The center conducts major outreach efforts targeting all ages and educational levels, with a special emphasis on under-represented groups in the sciences.

Research Highlights

The Center places particular emphasis on understanding factors that control environmental exposure to nanomaterials. Investigators seek to explain fundamental principles that determine nanoparticle surface chemistry, how the particles travel and how they transform in the environment and in contact with organisms. Researchers connect the chemistry and size-effects of nanoparticles to how and why they aggregate and move in the environment. The Center is characterizing biological and chemical transformations of such materials as a basis for understanding their environmental persistence, transport and bioavailability.

Center investigators examine the impact of nanomaterials on complex systems of organisms and their environment, looking at ecological endpoints to understand how nanoparticles are absorbed, their developmental impacts and their toxicity. Researchers, for example, at a scale never tried before, are studying how a complex environmental matrix will change the properties of nanomaterials. In preliminary data, they are finding that results in conventional lab experiments appear to be markedly different from those obtained in CEINT's mesocosms, a series of controlled ecosystems built outdoors where complex environments appear to have a dampening effect on nanomaterial impacts.

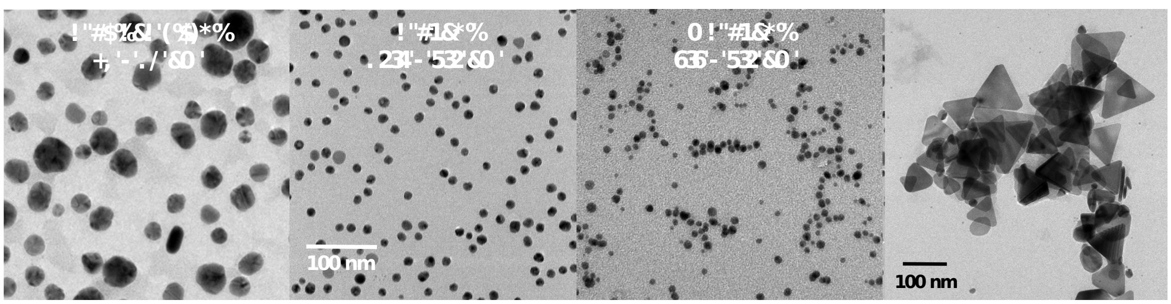
CEINT investigators are also constructing a comprehensive model of the potential environmental risks of nanomaterials, linking factors such as particle characteristics, transport, and ecological effects into a probabilistic framework (Bayesian Network). They not only want to assess ecological risks, but also to highlight the uncertainty that currently surrounds many of them. The work includes significant progress by CEINT to estimate the global production of different nanoparticles, including titanium dioxide, silver nanoparticles, and carbon nanostructures.

Notable Results

Real-World Testing: CEINT has constructed 30 tightly controlled and highly instrumented ecosystems, or "mesocosms," that are located in the Duke Forest, a campus research area. Each mesocosm is 3 ft. x 12 ft. and represents a wetland environment. Currently, a diverse field of

researchers, working on 26 different experiments, have added different types of nanoparticles to the mesocosms and are studying the resulting interactions and effects on plants, fish, bacteria and other elements within the contained systems. The scale and complexity of these systems necessitates extensive collaboration across many fields of science, bringing together engineers, ecologists, biologists and soil scientists who work together to address emerging threats to our environment.

Material Standardization and Characterization: The center maintains an online, ever expanding, catalogue of nanomaterials available to researchers. These materials are extensively characterized, with their properties rigorously maintained across manufacturing cycles. This catalogue ensures that materials used in CEINT are consistent across all participating institutions and experiments, eliminating experimental variance stemming from varying nanoparticle qualities. Furthermore, CEINT is capable of providing custom-fabricated materials for researchers interested in examining particular nanomaterial properties.



TEM images of silver nanoparticles custom made by CEINT.

Nanoparticles Building Up in the Food Chain: A study by CEINT investigators was the first to show that nanoparticles can build up in a land-based food chain. The concern is that so-called biomagnification, concentrations growing up a food web, may lead to greater toxicity, much as was found with mercury and some pesticides.

Research led by Prof. [Paul Bertsch] at the University of Kentucky found that gold nanoparticles in the soil accumulate in tobacco plants. The particles concentrate further in insects that eat the tobacco plants, the tobacco hornworm. The finding has important implications for risks associated with nanotechnology, including the potential for human exposure.

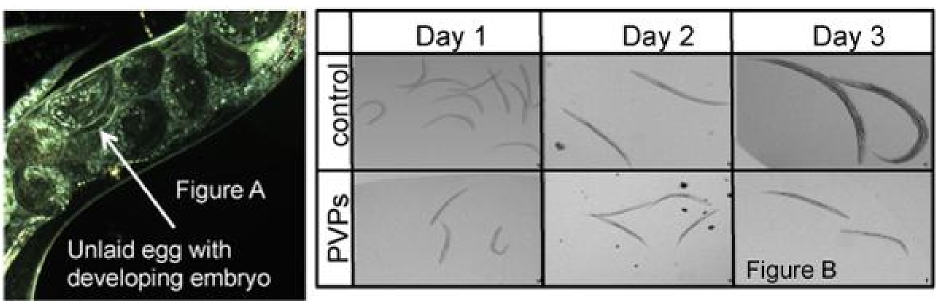
The increasing use of nanoparticles in consumer and industrial products is leading to more of the particles finding their way to wastewater. Evidence suggests that several classes of nanomaterials may accumulate in sludge derived from wastewater treatment, sludge that farmers often use to fertilize land. Those applications may prove a major pathway for the introduction of manufactured nanomaterials to the environment. (See *Environmental Science & Technology*, 2011.)

Particles built up in tobacco hornworms eating plants where the particles had accumulated.

Silver Nanoparticles Passed to Offspring: Modern stores carry many products with added silver nanoparticles to kill bacteria, including antimicrobial socks, paints, and even computer keyboards. Why silver nanoparticles kill bacteria is unclear, but their increasing use raises concern that their release into the environment could pose a toxic risk.

CEINT investigators studied the physical and chemical behavior of three silver nanoparticles with different sizes and coatings, and how they inhibit the growth of a particular organism, a nematode called C. elegans. Using traditional and novel analytical methods, the team led by Dr. Joel Meyer of Duke observed significant aggregation of the silver nanoparticles, dissolution of silver outside the organism, and how the nematodes absorb silver.

In one particularly significant finding, the investigators also found that silver nanoparticles were transferred to the worm's egg sacs—meaning the silver was transferred across generations.



Silver particles are taken up into the cells of a nematode (Fig. A), while exposure to the particles inhibits growth in the developing nematode (Fig. B).

Although all the tested silver nanoparticles passed cell membranes in C. elegans, at least part of the toxicity observed was mediated by ionic silver, a form in which a silver atom is missing an electron . (See *Aquatic Toxicology*, Oct. 15, 2010)

Education and Outreach: Nano2Earth is a high school curriculum initially funded by the NSF and developed by Prof. Michael Hochella and colleagues at Virginia Tech University. Nano2Earth introduces nanotechnology through studies of groundwater and is targeted for use in high school biology, chemistry and Earth science classes. CEINT supported refinement of the NSF funded Nano2Earth curriculum so that it could be submitted to National Science Teachers Association for review for publication. The curriculum consists of a set of five nano-science lessons, which can be taught as stand-alone lessons or as a whole curriculum. The materials span approximately three weeks of in-class instruction and activities. The curriculum booklet includes several introductory chapters that provide background on nanoscale science and technology. CEINT is seeking funding to create partnerships to hold teacher training workshops to optimize use of Nano2Earth curriculum nationally and beyond.