Nanomaterials in the Aquatic Environment: Persistence, Transformations, and Bioavailability

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Recent advances in nanotechnology have produced numerous and promising applications in all sectors of society, including energy, electronics, medicine, and consumer products. Nanomaterials and nano-enabled devices are proliferating at a rate that draws comparisons to the Industrial Revolution. While the quality-of-life improvements are indeed promising, the potential risks involved for environmental and human health are largely unknown.

Nanomaterials are defined as materials with at least one dimension smaller than 100 nm. They can consist of many types of geometric shapes including particles, tubes, rods, and plates. The unique traits of nanomaterials are not just the small length scales of the materials. Rather, nanomaterials possess relatively large specific surface areas and crystal lattice imperfections that create unique reactivities that would not occur with compositionally identical materials of larger dimensions. With discoveries of nano-specific properties and reactivity, nanotechnology has brought exciting and innovative applications, but also uncertainties with respect to environmental health and safety.

In recent years, environmental scientists, engineers, and toxicologists have made a concerted effort to understand the ecological and human health risks that would accompany large scale developments in nanotechnology. Much of this work is motivated by historical trends for environmental pollutants. In such cases, ground-breaking developments in technology (e.g. DDT pesticides, leaded gasoline, PCBs in electrical devices) have resulted in widespread degradation of ecosystems and endangerment of public health. These effects would typically be discovered after maturation and large scale implementation of the technology. In other words, realization of environmental impacts occurs at a stage when costs for remedial actions are the greatest. Current environmental research related to nanotechnology seeks to prevent future environmental disasters and to improve nano-enabled technology at the initial stages of product development.

Each phase of a nanomaterial’s lifetime (from the raw material, fabrication, product use, and disposal) can result in releases to the environment (e.g. air, water and soil). This talk will focus on the major pathways that govern the environmental fate of nanomaterials in aquatic settings such as sewage wastewater, streams, lakes, rivers, groundwater, etc. These pathways include transformations that must be considered as nanomaterials react with other constituents in natural waters. For example, nanomaterials can aggregate with other particles, deposit onto surfaces, dissolve and release ions, and catalyze reactions on their surfaces. These transformations would ultimately control the lifetimes of the nanomaterials in the environment and their potential toxicity towards organisms exposed to the nanomaterials. The reactions between metallic silver nanoparticles and natural organic matter will be discussed as an example of chemical reactions that influence the fate and bioavailability of nanoparticles in natural waters.

Much of the uncertainty in this area stems from unknown environmental release scenarios. Thus, environmental risk assessments of nanotechnology are based on exposure estimates that can vary by many orders of magnitude. Research on the potential dangers of engineered nanomaterials must also recognize that naturally-occurring nanomaterials are ubiquitous in most ecosystems. The geochemistry of natural nanomaterials can help inform predictions for the fate of their man-made counterparts. Another challenge for environmental scientists is to understand how the nano-specific characteristics of small particles influence their persistence and reactivity in the environment. In this case, knowledge and research tools developed from the nanosciences may be useful for environmental scientists. The ultimate objective of this collective work is to develop a scientific framework that will help environmental policy makers assess the persistence, transformations, and bioavailability of nanomaterials in the environment.