Microbial Impacts of Engineered Nanoparticles

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Abstract

Responsible usage of nanomaterials in commercial products and environmental applications, and prudent management of the associated risks, require an understanding of nanoparticle mobility, bioavailability and ecotoxicology. This project will elucidate processes governing the transport and microbial impacts of two classes of catalytic nanomaterials in soil-water systems: fullerenes and metallic nanoparticles (e.g., TiO2, ZnO and Fe (0)). Specific tasks include to: (1) characterize nanomaterials size, shape, functionality, reactivity, aggregation, deposition potential, and bioavailability; (2) screen nanomaterials of varying sizes and properties for bactericidal activity; (3) discern bacterial physiologic characteristics that confer resistance (or susceptibility) to catalytic nanomaterials; (4) evaluate the potential for fullerene biotransformation by reference bacteria and fungi; and (5) assess the impact of simulated nanomaterial releases on microbial diversity and community structure.

We postulate that reactivity at the nanometric scale is intimately linked to nanoparticle mobility and microbial sensitivity. Thus, first-order factors increasing nanoparticle reactivity should increase the rate of redox reactions with second-order effects on particle mobility and ecotoxicity. Sources of reactivity may include functionalization of nanoparticle surfaces, affinity for electron uptake and subsequent transfer to species in solution and, interfacial phenomena ranging from ordered water effects such as clathrate formation around nanoparticle nuclei to adsorption of naturally occurring macromolecules. Regarding microbial impacts, we hypothesize that nanomaterials that generate reactive oxygen species or related free radicals will hinder heterotrophic and photosynthetic activities and cause population shifts that reflect differential responses and diverse protective mechanisms used by dissimilar populations. Thus, aerobic bacteria with enzymes that destroy toxic oxygen species or with thicker cell walls may have a competitive advantage. Similarly, fermenting bacteria may be more resistant than respiring or photosynthetic bacteria, because the latter employ many biomolecules to transfer electrons during phosphorylation, which could interact with catalytic nanomaterials to generate harmful free radicals.

Regarding experimental approach, we will follow a risk assessment structure to examine factors that affect nanoparticle exposure and impact. Nanoparticle exposure will be quantified in terms of mobility in soil-water systems. Microbial impact will be quantified as a function of nanomaterial properties and bacterial physiological characteristics, by measuring cell growth, respiratory, photosynthetic and enzymatic activities. Molecular tools will be used to characterize effects on microbial community structure. The interface between exposure and impact will be examined in both batch reactors and in flow-through column experiments.

The relevance of the proposed work to the EPA mission is related to the fact that microorganisms are the foundation of all ecosystems and are often the basis for food chains and the main agents of biogeochemical cycles. Thus, understanding their interactions with engineered nanomaterials is important to ensure that nanotechnology improves material and social conditions without exceeding the ecological capabilities that support them. At the conclusion of this project, we will have an improved understanding of the chemical and physical factors that control nanoparticle mobility and bioavailability, and their impacts on microbial activities, diversity and community structure. This will benefit risk assessment and management efforts, and may contribute indirectly to the development of nanotechnology-based disinfection and biofouling control strategies.