Environmental nanotoxicology: Where are we now?

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Editorial

I recently attended the sixth Sustainable Nanotechnology Organization (SNO) Conference from November 5-7, 2017. When I was a Ph.D. student at Northwestern University, I attended the inaugural SNO conference in 2012, from when this conference has witnessed the development and evolution of the Environmental Nanotoxicology field. This year, the SNO conference honoured Professor Pedro Alvarez of Rice University, who made great and indispensible contribution to both applications and implications of nanomaterials (NMs). This reminded me of his pioneering work on comparative eco-toxicity of metal oxide NMs to bacteria (Adams et al., Water Research, 2006, total citations > 1000) [1], the earliest publication on environmental Nanotoxicology I could remember. So, 5 years after the first SNO conference and 11 years after Professor Alvarez's inspiring work, what does the Environmental Nanotoxicology field look like now? What have we learned from the past? And what should we do as a researcher at present and in the future? In my personal perspective, the following aspects are highlighted in this Editorial.

Firstly, characterization of NMs has been significantly improved in toxicological studies. This is not trivial because the toxicities of NMs are tightly related to their physicochemical properties. In early studies, scientists were trying to understand whether NMs are more toxic than their bulk counterparts due to their smaller sizes. As a result, nanomaterial characterization was mainly focusing on the primary (and also aggregate) sizes of NMs. As more studies have been performed on a diverse set of NMs, we have realized that other material properties, such as morphology [2-4], surface charge [5,6], and functionality[7-9], markedly influence the reactivities and toxicities of NMs. For example, my previous work demonstrates that material morphology and dimensionality regulate the phototoxicity of nano-TiO_2 by governing how nano-TiO_2 particles align at the bacterial cell surface [4]. Thanks to the interdisciplinary collaboration among material scientists, toxicologists, and environmental scientists, a detailed characterization of tested NMs has been achieved and become a necessary routine in most publications on Nanotoxicology nowadays. This progress has greatly promoted our mechanistic understanding of NM toxicities and potentially establishes a structure-function-toxicity relationship that guides the design of sustainable NMs with mitigated toxicities.

Secondly, the importance of environmental transformations has been recognized in the Environmental Nanotoxicology community. Once entering the environment, NMs are subjected to various physical, chemical, and biological transformations, which alter the properties, activities, bioavailability, and toxicities of NMs [10]. One notable example is the influence of solution chemistry on the toxicities of metal nanoparticles such as nanoscaled silver (Nano-Ag) [11,12]. The concentrations of Cl^-, S^{2-}, and thiol-containing substances have been shown to significantly change the fate, speciation, and toxicity of Nano-Ag [11-13], due to their strong complexing capabilities to Ag ions. Several state-of-the-art techniques, such as high-resolution transmission electron microscopy (HR-TEM) [14] and synchrotron-based X-ray absorption spectroscopy (XAS) [15-17], have been employed to understand the environmental transformations of NMs. The resulting findings confirm drastic alteration of NMs in the environment, emphasizing the importance of environmental transformations in assessing the toxicity and ecological risks of NMs.

Thirdly, environmental nanotoxicology research is moving towards more realistic scenarios. Most of the early studies on nanotoxicology were performed in the laboratory, and the applied NM concentrations could be orders of magnitude higher than the predicted environmental concentrations. Holden et al. critically evaluated the environmental relevance of current hazard assessment on NMs, pointing out that several uncertainties exist in terms of predicted environmental concentrations, bioavailability, and effective toxic concentrations of NMs [18]. Fortunately, chronic studies with more environmentally meaningful concentrations are increasingly adopted to simulate prolonged exposure of NMs at low concentrations in the environment [19-21]. Also, researchers are moving beyond traditional viability-based toxicological tests to investigate the sub-lethal effects using more appropriate and diverse bio-receptors [22-26]. Furthermore, more studies have focused on characterizing and detecting NMs present in the environment [27-30]. New technologies, such as single-particle inductively coupled plasma mass spectrometry (SP-ICP-MS), are emerging as powerful tools that enable quantification of NMs contained in environmental samples [31-33].

However, the Environmental Nanotoxicology community is still facing many challenges. More information still needs to be gathered to inform a meaningful regulatory framework on NMs. Since the toxic effects of NMs are a function of both NM properties and experimental condition, a standardized testing procedure or inter-laboratory comparison will be of great value to improve the reliability and consensus of toxicological data associated with NMs. Also, due to the rapid development of nanotechnology, myriad novel NMs (e.g., two-dimensional NMs [34], hybrid NMs [35,36]) are being designed, produced, and incorporated into numerous industrial and commercial products. Thus, the utilization of more efficient approaches (e.g., high-throughput screening [37]) will help facilitate our pace of understanding the ecological and health effects of NMs. Last but not least, we are still lack of enough technologies that characterize both concentrations and properties of NMs in the environment accurately. In particular, we need to developmethods that are able to distinguish engineered NMs from those inherently present in nature. In order to achieve this goal, a combination of analytical, spectroscopic, and microscopic tools will be likely employed to provide a comprehensive picture of NMs in complex environmental matrices.

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