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Editorial

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Impact of Engineered Nanoparticles on Aquatic Organisms

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Nanotechnology is one of the fastest growing technologies. It is expected to become a trillion US dollar industry within the next decade. According to the British Standards Institution, the American Society for Testing Materials, and the Scientific Committee on Emerging and Newly-Identified Health Risks, engineered nanoparticles (ENPs) have a dimension between 1 to 100nm and poses unique physical and chemical properties compared to their larger counterparts. Due to these novel properties, a wide range of new industrial applications for ENPs have been developed including: drug delivery, medical devices, food, cosmetics, agriculture chemicals and inputs, water purification and decontamination as well a range of applications in electronics and materials science. The wide and expanding application of ENPs may result in their release into the aquatic environment with exposure to aquatic organisms posing a risk that remains poorly understood. For drug and agricultural applications, the attractiveness of ENPs is the greater bioactivity.

While there are regulatory limits on the release of ENP components, there has yet to be modification of regulations taking into account the differences in the biological activity of ENPs compared to either their more common solid forms. There are few studies assessing the risk of ENPs in the aquatic environment. These studies suggest that ENPs are toxic to fish at least to some degree; this includes ENPs comprised of: carbon nanotubes, carbon spheres called fullerenes (C_{60}) and metal oxide NPs of titania, silica, aluminum oxide, silver, gold and zinc oxide.

Since ENPs can end up in aquatic environments by various routes, there are potentially many different ways by which aquatic organisms could become contaminated. Different methods have been used by researchers studying the ENPs toxicity of organisms in aquatic environments including: acute exposure, chronic exposure, fish cell line culture, and food chain and dietary exposure. ENPs physically adhere to the skin, eye, eggs, gills, and scale causing morphological malformation that result in various injuries, spinal abnormalities, finfold abnormalities, and heart malformations. Erosion of the intestinal epithelia has been observed in food chain and dietary exposure studies in fishes. Gill edema and thickening of lamellae have also been observed from ENP exposure. Metabolic processes are also altered from exposure to ENPs. For example, Na^+K^+-ATPase activity decreases in the gill and intestine, thiobarbituric acid reactive substances (TBARS), a sign of oxidation, increase in a concentration-dependent manner in gill, intestine and brain, but not in liver in fish exposed to the ENPs; oxidative stress is particularly prominent in early life stages. Chromosomal aberrations and aneuploidy have been reported in aquatic organisms exposed to ENPs, and other signs of cytotoxicity and genotoxicity from exposure of fish to ENPs in fish have been found.

The toxicity of ENPs to organisms in the aquatic environment is governing by different parameters, including:

- Exposure media: The pH, composition, presence and concentration of divalent cations (total hardness of the water), and the ionic strength (for example, NaCl concentration in freshwater or seawater) in the aquatic media will affect the ENPs surface charge and therefore their agglomeration rate and ability of the ENPs to physical adhere to tissue surfaces. In *in vitro* studies, cell lines were exposed to the ENPs in cell culture media of differing pH and ionic strength, but not all relevant environmental exposure conditions were controlled in these studies. In the environment, multiple ENPs may be present and ENPs properties would be altered depending upon the characteristics of the exposure media, therefore the behavior of ENPs under a complex set of conditions must be considered. Due to this, different ENPs dose metric studies should be conducted in different media that simulate both fresh water and marine environments. Understanding whether ENPs remain in the nanoparticle state in the aquatic environment or whether they agglomerate or are present in some other form needs to be investigated.
- Size and surface area: ENPs are less than 100nm in at least one dimension, and usually have significantly different surface properties than materials of similar chemical composition that are larger. Size and surface properties influence nanoparticle toxicity. Many studies have shown that smaller sized particles are more toxic than larger sized particles. Smaller sized ENPs can be transported into the cells and tissues.
- Surface chemistry: Different aspects of ENPs surface chemistry such as catalytic activity, ability to generate reactive species and general cytotoxicity have been studied and studies showed that these are dominant factors in determining toxicity.
- Shape: ENPs shape also play an important role in their toxicity. For example, dendritic clusters of Ni-NP are more toxic than spherical forms.
- Concentration: Concentration of ENPs in the aquatic environments is another parameter that affects toxicity. At higher ENP concentration (e.g. 1 mg/L of one particular ENP) physical injuries such as gill edema, thickening of lamellae and embryonic injuries and high mortality are reported. At lower concentrations (5-50 µg/L), sub-lethal effects including physiological changes in Na^+K^+-ATPase activity, membrane lipid oxidation as shown by an increased concentration of thiobarbituric acid reactive substances (TBARS), other signs of oxidative stress, chromosomal aberrations and aneuploidy could be observed, but no mortality. Osmoregulation in migratory fish depends on Na^+K^+-ATPase. According to the studies, ENPs can decrease Na^+K^+-ATPase in gill, however, its effect on fish migration, has not been considered.

Until recently, little attention has been paid to potential risks associated with exposure of aquatic organisms to ENPs and the

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corresponding need for relevant *in vitro* models. ENPs in the environment are present at low levels, and there are different possibilities for aquatic organisms to be exposed to ENPs, including via the food chain and through adsorption orally or through the gills or lateral line. Due to this, more studies are required to determine the effect of ENPs from chronic low level exposure, bioaccumulation, and the potential for depuration in addition to acute toxicity studies.

Additional studies should be conducted including but not limited to the following:

- Ontogenic studies examining embryonic, larvae, juvenile, and mature stages are necessary. In addition, ethological studies in fishes should be conducted.
- Feeding behavior, migration and propagation are olfactory system-dependent, however, the effect of ENPs on olfactory system, has not been studied.
- The effect of ENPs on the lateral line which serves an important role in schooling behavior, predation, and orientation, should also be studied.
- In addition, the effect of ENPs on metamorphosis and development in some fish such as sturgeon should be studied.
- There have been several studies conducted on phyto- and zoo-planktons, but no studies in benthic organisms. ENPs can be adsorbed by organic matter in aquatic environment particularly in sediments. Since, benthic organisms play important roles in chemical circulation, and as a food source for aquatic organisms, the effect of ENPs on them should be considered.

In summary, the impact of ENPs on organisms in the aquatic environment needs to be evaluated as technologies employing these materials develop. Only with rigorously conducted experimental science will it be possible to obtain the data necessary for environmental risk assessment and a determination as to whether or not ENPs pose a potential or a *de minimis* risk.

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