Nanotechnology Safety

The purpose of this document is to provide the George Washington University (GW) community with current information regarding key environmental health and safety implications of nanomaterials and to provide University researchers who work with nanomaterials guidance, in the absence of state or federal regulations, in working with nanoscale materials, so that they may do so in a safe manner. If you currently work with nanoscale materials or plan to work with nanoscale materials in the future see below for OLS interim guidelines.

What is nanotechnology and what are nanomaterials?

Nanotechnology is the manipulation of matter on a near---atomic scale to produce new structures, materials, and devices. This technology has the ability to transform many industries and can be applied in many ways to areas ranging from medicine to manufacturing. Research in nanoscale technologies is growing rapidly worldwide. Lux Research [2007] projects that new emerging nanotechnology applications will affect nearly every type of manufactured product through the middle of the next decade, becoming incorporated into 15% of global manufacturing output, totaling $2.6 trillion in 2014.

Nanomaterials present new challenges to understanding, predicting, and managing potential health risks to workers. As with any material being developed, scientific data on the health effects in exposed workers are largely unavailable. In the case of nanomaterials, the uncertainties are great because the characteristics of nanoparticles may be different from those of larger particles with the same chemical composition. Safety and health practitioners recognize the critical lack of specific guidance on the safe handling of nanomaterials—especially now, when the degree of risk to exposed workers is unknown. In the meantime, the extensive scientific literature on airborne particles—including toxicology and epidemiological studies, measurement techniques, and engineering controls—provides the best available data from which to develop interim approaches for working safely with nanomaterials and to develop hypotheses for studies of new nanomaterials.

The National Institute for Occupational Safety and Health (NIOSH) is working in parallel with the development and implementation of commercial nanotechnology through (1) conducting strategic planning and research, (2) partnering with public--- and private---sector colleagues from the United States and abroad, and (3), making information widely available. The NIOSH goal is to provide national and world leadership for incorporating research findings about the implications and applications of nanotechnology into good occupational safety and health practice for the benefit of all nanotechnology workers. NIOSH has developed a strategic plan for coordinating nanotechnology research and for use as a guide for enhancing the development of new research efforts (www.cdc.gov/niosh/topics/nanotech/strat_plan.html).

Types of Nanomaterial's:

- Nano---object is defined as material with one, two, or three external dimensions in the size range from approximately 1–100 nm. Subcategories of nano---object are (1) nanoplate, a nano---object with one external dimension at the nanoscale; (2) nanofiber, a nano---object with two external dimensions at the nanoscale with a nanotube defined as a hollow nanofiber and a nanorod as a solid nanofiber; and (3) nanoparticle, a nano---object with all three external dimensions at the nanoscale. Nano---objects are commonly incorporated in a larger matrix or substrate referred to as a nanomaterial. Nano---objects may be suspended in a gas (as a nanoaerosol), suspended in a liquid (as a colloid or nanohydrosol), or embedded in a matrix (as a nanocomposite). The precise definition of particle diameter depends on particle shape as well as how the diameter is measured.

Particle morphologies may vary widely at the nanoscale. For instance, carbon fullerenes represent nano---objects with identical dimensions in all directions (i.e., spherical), whereas single---walled carbon nanotubes (SWCNTs) typically form convoluted, fiber---like nano---objects. Many regular but nonspherical particle morphologies can be engineered at the nanoscale, including flower--- and belt---like structures. Please see www.nanoscience.gatech.edu/zlwang/research.html for examples of some nanoscale structures.

- Ultrafine Particles: The term ultrafine particle has traditionally been used by the aerosol research and occupational and environmental health communities to describe airborne particles smaller than 100 nm in diameter. Ultrafine is frequently used in the context of nanometer---diameter particles that have not been intentionally produced but are the incidental products of processes involving combustion, welding, or diesel engines (see Figure 4–1). The term nanoparticle is frequently used with respect to particles demonstrating size---dependent physicochemical properties, particularly from a materials science perspective. The two terms are sometimes used to differentiate between engineered (nanoparticle) and incidental (ultrafine) nanoscale particles.

- Engineered Nanoparticles: Engineered nanoparticles are intentionally produced, whereas ultrafine particles (often referred to as incidental nanoparticles) are typically byproducts of processes such as combustion and vaporization. Engineered nanoparticles are designed with very specific properties or compositions (e.g., shape, size, surface properties, and chemistry). Incidental nanoparticles are generated in a relatively uncontrolled manner and are usually physically and chemically heterogeneous compared with engineered nanoparticles.

- Nanoaerosol: A nanoaerosol is a collection of nanoparticles suspended in a gas. The particles may be present as discrete nano---objects, or as aggregates or agglomerates of nano---objects. These agglomerates may have diameters larger than 100 nm. In the case of an aerosol consisting of micrometer---diameter particles formed as agglomerates of nano---objects, the definition of nanoaerosol is open to interpretation. It is generally accepted that if the nanostructure associated with the nano---object is accessible (through physical, chemical, or biological interactions), then the aerosol may be considered a nanoaerosol. However, if the nanostructure within individual micrometer---diameter particles does not directly influence particle behavior (for instance, if the nanoparticles were inaccessibly embedded in a solid matrix), the aerosol would not be described as a nanoaerosol.

- Agglomerate: Agglomerate is a group of nanoparticles held together by relatively weak forces, including van der Waals forces, electrostatic forces, and surface tension [ISO 2006].

- Aggregate: An aggregate is a heterogeneous particle in which the various components are held together by relatively strong forces, and thus not easily broken apart [ISO 2006]. Aggregated nanoparticles would be an example of a nanostructured material.

Nanomaterials are already being used in a number of industries, including the electronic, biomedical, pharmaceutical, cosmetic, energy, catalytic and materials industries. Nanomaterials are often combined with other materials today to improve product functionality. Nanotechnology also has the potential for reducing pollution, reducing energy consumption, and cleaning up pollution. However, with the advent of these new materials, unforeseen environmental issues or occupational hazards could arise. Researchers must be extremely careful when working with new materials having unknown properties and toxicity.

Health Hazards With Exposure to Nanoparticles

Current scientific evidence indicates that nanoparticles may be more biologically reactive than larger particles of similar chemical composition and thus may pose a greater health risk when inhaled. Some studies have suggested that the skin is also a potential route of exposure for nanoparticles. The potential health risk following exposure to a substance is generally associated with the magnitude and duration of the exposure, the persistence of the material in the body, the inherent toxicity of the material, and the susceptibility or health status of the person. The uncertainties regarding health risks with exposures to nanomaterials arise because of the gaps in knowledge about routes of exposure, and the fate of these materials once they are inside the body. Because of these uncertainties, it is important that interim precautionary measures be taken to minimize exposures. The fate of nanoparticles in the environment and subsequent human exposures is also largely unknown.

- Nanomaterials may enter the body by routes not typically found with other chemicals because of their small size.
- If nanomaterials of certain sizes are able to enter the body, they may pass through cell membranes or cross the blood---brain barrier because of their small size. In some cases this is a beneficial characteristic when used for drug delivery and disease treatments. This characteristic could also result in unintended impacts for manufactured nanomaterials not designed for disease therapies.
- Nanomaterials may interact with environmental media and pollutants to produce by---products that may have the potential to cause health effects.

As with all toxicological assessment, it will be necessary to develop information on:

- Route of exposure (inhalation, oral, or dermal) that carries the greatest risk
- Physical and chemical characterization of nanomaterials
- Dose–response relationship of manufactured nanomaterials and toxicity

Characteristics of nanoparticles are relevant for health effects

Studies specifically dealing with the toxicity of nanoparticles have only appeared recently and are still scarce. Most of the information available comes from studies on inhaled nanoparticles and from pharmaceutical studies in which nanomaterials are used, among other things to improve drug delivery.

The characteristics of nanoparticles that are relevant for health effects are:

- *Size* – In addition to being able to cross cell membranes, reach the blood and various organs because of their very small size, nanoparticles of any material have a much greater surface to volume ratio (i.e. the surface area compared to the volume) than larger particles of that same material. Therefore, relatively more molecules of the chemical are present on the surface. This may be one of the reasons why nanoparticles are generally more toxic than larger particles of the same composition.

- *Chemical composition and surface characteristics* – The toxicity of nanoparticles depends on their chemical composition, but also on the composition of any chemicals adsorbed onto their surfaces. However, the surfaces of nanoparticles can be modified to make them less harmful to health.

- *Shape* – Although there is little definitive evidence, the health effects of nanoparticles are likely to depend also on their shape. A significant example is nanotubes, which may be of a few nanometres in diameter but with a length that could be several micrometres. A recent study showed a high toxicity of carbon nanotubes that seemed to produce harmful effects by an entirely new mechanism, different from the normal model of toxic dusts.

Minimizing aerosolization of nanomaterials and best work practices

Working with nanomaterials in liquid media during pouring or mixing operations, or where a high degree of agitation is involved, grinding or degrading nanomaterials embedded in a solid matrix, and generating nanoparticles in the gas phase in non-enclosed systems all have the potential to aerosolize nanoparticles. Maintenance work on equipment used to produce or fabricate nanomaterials and the cleaning of dust collection systems used to capture nanoparticles also have the potential to aerosolize particles and should be considered as a potential source of inhalation exposure.

Do not eat or drink in areas where nanomaterials are handled or processed. Wash hands thoroughly with soap and water when you have completed experimental procedures and before leaving the laboratory. Fires and explosions are a potential safety concern with nanoparticles, so it is extremely important to avoid processes that generate significant quantities of dust.

Interim Guidelines for the Safe and Environmentally Responsible Laboratory Use of Nanomaterials

Since it is not known how much exposure to nanoparticles is safe, it is important to follow the precautionary principles and use procedures that minimize all routes of exposure (inhalation, skin contact, and ingestion). Currently, material safety data sheets (MSDS) may not provide accurate or helpful information. **If you work with or plan to work with nanoscale materials, please contact the GW Lab Safety Officer at Office of Laboratory Safety at labsafety@gwu.edu.** By observing your specific laboratory practices, we can provide you with customized recommendations to minimize environmental and safety threats. Accordingly, the following interim guidelines are provided to aid personnel in conducting safe, environmentally responsible research activities:

Additional Resources

There are a number of resources available online that provides information on current research on the toxicity of nanomaterials and current best practices when working with nanomaterials. We will continue to review websites and articles of interest to add them to this site for reference. We ask that anyone conducting nano---related research on grounds contact OLS first, so that we may observe laboratory practices and assist personnel in evaluating any processes with potential for exposure.

General Safe Practices for Working with Engineered Nanomaterials in Research Laboratories --- DHHS/CDC/NIOSH
International Council on Nanotechnology --- Up---to---date postings and searchable datable of nanotoxicology research
National Institute for Occupational Safety and Health (NIOSH) --- Nanotechnology Topic Page
The National Nanotechnology Initiative (NNI) --- Federal R&D program established to coordinate the multiagency efforts in nanoscale science, engineering, and technology