NIOSH Safety and Health Topic:

Nanotechnology

Approaches to Safe Nanotechnology: An Information Exchange with NIOSH

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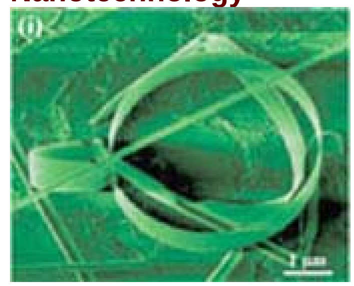
Nanotechnology



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Introduction

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 to be applied in many ways to areas ranging from medicine to manufacturing. Research in nanoscale technologies is growing rapidly worldwide. By 2015, the National Science Foundation estimates that nanotechnology will have a $1 trillion impact on the global economy and will employ 2 million workers, 1 million of which may be in the United States [Roco and Bainbridge 2001].

Nanomaterials present new challenges to understanding, predicting, and managing potential health risks to workers. As with any new 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 nanomaterials may be different from those of the larger materials with the same chemical composition.** Safety and health practitioners recognize the critical lack of 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.

Intent and Purpose

With the launch of the *Approaches to Safe Nanotechnology* Web page, NIOSH hopes to do the following:

- **Raise awareness** of the occupational safety and health issues being identified in the rapidly moving and changing science involving implications and applications of nanotechnology.
- **Use the best information available to make interim recommendations** on occupational safety and health practices in the production and use of nanomaterials. These interim recommendations will be updated as appropriate to reflect new information. They will address key components of occupational safety and health, including monitoring, engineering controls, personal protective equipment, occupational exposure limits, and administrative controls. They will draw from the ongoing NIOSH assessment of current best practices, technical knowledge, and professional judgment. Throughout the development of these guidelines, the

utility of a hazard-based approach to risk assessment and control will be evaluated and, where appropriate, recommended.

- **Facilitate an exchange of information** between NIOSH and its external partners from ongoing research, including success stories, applications, and case studies.
- **Respond to requests** from industry, labor, academia, and other partners who are seeking science-based, authoritative guidelines.
- **Identify information gaps** where few or no data exist and where research is needed.

The NIOSH Web site will serve as a starting point for developing good work practices and will set a foundation for developing proactive strategies for the responsible development of nanotechnologies in the U.S. workplace. This site will be dynamic in soliciting stakeholder input and featuring regular updates.

Scope

This document has been developed to provide a resource for stakeholders who wish to understand more about the safety and health applications and implications of nanotechnology in the workplace. The information and guidelines presented here are intended to aid in evaluating the potential hazard of exposure to engineered nanomaterials and to set the stage for the development of more comprehensive guidelines for reducing potential workplace exposures in the wide range of tasks and processes that use nanomaterials. The information in this document will be of specific interest to the following:

- Occupational safety and health professionals who must (1) understand how nanotechnology may affect occupational health and (2) devise strategies for working safely with nanomaterials
- Researchers working with or planning to work with engineered nanomaterials and studying the potential occupational safety and health impacts of nanomaterials
- Policy and decision-makers in government agencies and industry
- Risk evaluation professionals
- People working with or potentially exposed to engineered nanomaterials in the workplace

In making this document available, NIOSH is requesting data and information from key stakeholders that is relevant to the development of occupational safety and health guidelines. The purpose will be to develop a complete resource of occupational safety and health information and recommendations for working safely with nanomaterials based on the best available science. Particular attention will be given to questions about the potential health risks associated with exposure to nanoparticles and to the steps that can be taken to protect worker health. The information provided in this document has been abstracted from peer-reviewed literature currently available. **This document and resulting guidelines will be systematically updated by NIOSH as new information becomes available from NIOSH research or others in the scientific community.**

Established safe work practices are generally based on an understanding of the hazards associated with the chemical and physical properties of a material. Engineered nanomaterials may exhibit unique properties that are related to their physical size, shape, and structure as well as chemical composition. Considerable uncertainty still exists as to whether these unique properties involve occupational health risks. Current information about the potential adverse health effects of engineered nanomaterials, exposure assessment, and exposure control is limited. However, the large body of scientific literature that exists on exposures and responses to ultrafine and other airborne particles in animals and humans may be useful in making preliminary assessments as to the health risks posed by engineered nanomaterials. **Until further information is available, interim safe working practices should be developed based on the best available information.** The information and recommendations in this document are intended to aid in assessment of the potential hazard of engineered nanomaterials and to set the stage for the development of more comprehensive guidelines for reducing potential workplace exposures.

Descriptions and Definitions

Nanotechnology involves the manipulation of matter at nanometer* scales to produce new materials, structures, and devices. The U.S. National Nanotechnology Initiative (NNI) (see nano.gov/html/facts/whatIsNano.html) defines a technology as nanotechnology only if it involves all of the following:

1. Research and technology development involving structures with at least one dimension in the range of 1 to100 nanometers (nm), frequently with atomic/molecular precision

2. Creating and using structures, devices, and systems that have unique properties and functions because of their nanometer-scale dimensions

3. The ability to control or manipulate on the atomic scale

Nanotechnology is an enabling technology that offers the potential for unprecedented advances in many diverse fields. The ability to manipulate matter at the atomic or molecular scale makes it possible to form new materials, structures, and devices that exploit the unique physical and chemical properties associated with nanometer-scale structures. The promise of nanotechnology goes far beyond extending the use of current materials. New materials and devices with intricate and closely engineered structures will allow for (1) new directions in optics, electronics, and optoelectronics; (2) development of new medical imaging and treatment technologies; and (3) production of advanced materials with unique properties and high-efficiency energy storage and generation.

Although nanotechnology-based products are generally thought to be at the pre-competitive stage, an increasing number of products and materials are becoming commercially available. These include nanoscale powders, solutions, and suspensions of nanoscale materials as well as composite materials and devices having a nanostructure. An inventory of such products was compiled by the Woodrow Wilson Center's Project on Emerging Nanotechnologies (www.nanotechproject.org/44/consumer-nanotechnology).

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*1 nanometer (nm) = 1 billionth of a meter (10!9).

Nanoscale titanium dioxide, for instance, is finding uses in cosmetics, sun-block creams, and self-cleaning windows. And nanoscale silica is being used as filler in a range of products, including dental fillings. Recently, a number of new or "improved" consumer products using nanotechnology have entered the market—for example, stain and wrinkle-free fabrics incorporating "nanowhiskers," and longer-lasting tennis balls using butyl-rubber/nanoclay composites. Issues have been raised about the adequacy of testing and labeling requirements for nanomaterials used in consumer products [The Royal Society, The Royal Academy of Engineering 2004]. Further details on current and anticipated products can be found at www.nano.gov/html/facts/appsprod.html and www.nanotechproject.org/44/consumer-nanotechnology.

A. Nanoparticles

Nanoparticles are particles having a diameter between 1 and 100 nm. Nanoparticles may be suspended in a gas (as a nanoaerosol), suspended in a liquid (as a colloid or nano-hydrosol),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 nanoparticles with identical dimensions in all directions (i.e., spherical), whereas single-walled carbon nanotubes (SWCNTs) typically form convoluted, fiber-like nanoparticles with a diameter below 100 nm. Many regular but nonspherical particle morphologies can be engineered at the nanoscale, including "flower" and "belt"-like structures. For examples of some nanoscale structures, see www.nanoscience.gatech.edu/zlwang/research.html

B. Ultrafine particles

The term "ultrafine particle" has traditionally been used by the aerosol research and occupational and environmental health communities to describe airborne particles typically smaller than 100 nm in diameter. Although no formal distinction exists between ultrafine particles and nanoparticles, **the term "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.** Likewise, the term "nanoparticle" is frequently used with respect to particles demonstrating size-dependent physicochemical properties, particularly from a materials science perspective, although no formal definition exists. As a result, the two terms are sometimes used to differentiate between engineered (nanoparticle) and incidental (ultrafine) nanoscale particles.
It is currently unclear whether the use of source-based definitions of nanoparticles and ultrafine

particles is justified from a safety and health perspective. This is particularly the case where data on nonengineered, nanometer-diameter particles are of direct relevance to the impact of engineered particles. An attempt has been made in this document to follow the general convention of preferentially using the term “nanoparticle” in the context of intentionally-produced or engineered nanoscale particles and the term “ultrafine” in the context of incidentally-produced particles (e.g., combustion products). However, this does not necessarily imply specific differences in the properties of these particles as related to hazard assessment, measurement, or control of exposures, and this remains an active area of research. “Nanoparticle” and “ultrafine” are not rigid definitions. For example, since the term “ultrafine” has been in existence longer, some intentionally-produced particles with primary particle sizes in the nanosize range (e.g., TiO2) are often called “ultrafine” in the literature.

C. Engineered nanoparticles

Engineered nanoparticles are intentionally produced, whereas incidental nanoscale or ultrafine particles are byproducts of processes such as combustion and vaporization. Engineered nanoparticles are designed with very specific properties (including shape, size, surface properties, and chemistry), and collections of the particles in an aerosol, colloid, or powder will reflect these properties. Incidental nanoscale particles are generated in a relatively uncontrolled manner and are usually physically and chemically heterogeneous compared with engineered nanoparticles.

D. Nanoaerosol

A nanoaerosol is a collection of nanoparticles suspended in a gas. The particles may be present as discrete nanoparticles, or as assemblies (aggregates or agglomerates) of nanoparticles. These assemblies may have diameters larger than 100 nm. In the case of an aerosol consisting of micrometer-diameter particles formed as agglomerates of nanoparticles, the definition of nanoaerosol is open to interpretation. It is generally accepted that if the nanostructure associated with the nanoparticles 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.

E. Agglomerate

An agglomerate is a group of particles held together by relatively weak forces, including van der Waals forces, electrostatic forces and surface tension [ISO 2006].

F. 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].

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