UAH NANOMATERIALS SAFETY MANUAL

Nanotechnology is the field of science dealing with material specifically engineered to sizes of 100 nanometers (ηm – 10-9 m) or less. Information presented in this document provide guidance to maintain health and safety while working with nanomaterials.

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Table of Contents

Introduction

Nanotechnology is the field of science dealing with material specifically engineered to sizes of 100 nanometers (ηm – 10^{-9} m) or less. Nanotechnology is "the understanding and control of matter at the nanoscale, at dimensions between approximately 1 and 100 nanometers (nm)". A nanometer is one billionth of a meter, which is near-atomic scale. Engineered nanomaterials are assembled from nanoscale structures such as carbon nanotubes and filaments or from nanoparticles of materials such as titanium dioxide or cadmium selenide.

Classification of Nanomaterials

Nanomaterial (NM): nano-sized material having at least one external dimension in the size range of 1-100 nanometers. NMs include nanoparticles (NPs), nanostructured materials and ultrafine particles, and their agglomerates and aggregates.

Nanoparticle (NP): NM having all three external dimensions in the size range of 1-100 nanometers and its physicochemical properties are distinctly different than its bulk material of the same composition.

Nanostructured material: NM having distinct structural elements with dimensions in the size range of 1 to 100 nm. Nanostructured materials include nano-sized clusters, nano-crystallites or molecular composites.

Ultrafine particles: aerosolized NMs including incidental NPs derived from aerosols and their agglomerates are defined as ultrafine particles.

Agglomerates: group of NPs held together by weak interactions, such as Van der Waals forces, electrostatic forces and surface tension such that NPs are separated relatively easily with mild perturbation.

Aggregates: heterogeneous NPs in which various components are not easily separated as they are held together by relatively strong forces.

Different Type of Nanomaterials

Nanoparticles fall into three major groups: natural, incidental, and engineered.

Naturally Occurring

- Forest Fires
- Sea spray
- Mineral composites
- Volcanic ash
- Viruses

Human Origin (Incidental)

Incidental nanoparticles are often by-products produced as a result of industrial processes.

- Cooking smoke
- Diesel exhaust

- Welding fumes
- Industrial effluents
- Sandblasting

Human Origin (Engineered)-Nanotechnology

These are materials that have been specifically designed for function, such as fullerene C_{60}, which is used for fuel cell applications.

- Metals
- Quantum dots
- Buckyballs
- Nanotubes
- Sunscreen pigments
- Nanocapsules

OSHA-Identified Nanomaterial Standards

- 1904, Recording and reporting occupational injuries and illness
- 1910.132, Personal protective equipment, general requirement
- 1910.133, Eye and face protection
- 1910.134, Respiratory protection
- 1910.138, Hand protection
- 1910.141, Sanitation
- 1910.1200, Hazard communication
- 1910.1450, Occupational exposure to hazardous chemicals in laboratories
- Certain substance-specific standards (e.g., 1910.1027, Cadmium)

Potential Hazards

Information from research and animal studies on nanomaterials has identified some potential safety hazards and health effects. Because nanotechnology is a rapidly emerging field, more information will likely become available about potential health and safety hazards associated with some nanomaterials. The health hazard potential depends on the particular nanomaterial and a person's exposure level NIOSH (National Institute for Occupational Safety and Health) has determined the following potential exposure and health concerns:

- Nanomaterials have the greatest potential to enter the body through the respiratory system if they are airborne and in the form of respirable-sized particles (nanoparticles). They may also come into contact with the skin or be ingested.
- Based on results from human and animal studies, airborne nanoparticles can be inhaled and deposited in the respiratory tract; and based on animal studies, nanoparticles can enter the blood stream, and translocate to other organs.
- Experimental studies in rats have shown that equivalent mass doses of insoluble incidental nanoparticles are more potent than large particles of similar composition in causing pulmonary inflammation and lung tumors. Results from in vitro cell culture studies with similar materials are generally supportive of the biological responses observed in animals.

- Studies in workers exposed to aerosols of some manufactured or incidental microscopic (fine) and nanoscale (ultrafine) particles have reported adverse lung effects including lung function decrements and obstructive and fibrotic lung diseases. The implications of these studies to engineered nanoparticles, which may have different particle properties, are uncertain.

Routes of Occupational Exposure:

Inhalation

Inhalation has been a major focus of the nanotoxicology community; Nanoparticle (NP) penetration into the lung depends on its aggregation state. Airborne NPs can be inhaled and deposited in the respiratory tract. Inhaled NPs may enter the blood stream and translocate to other organs.

Certain nanomaterials can:

- Induce cancers, including mesothelioma
- Cause rapid and persistent pulmonary fibrosis
- Cause cardiovascular dysfunction
- Migrate along the olfactory nerve into the brain

Nanoparticles should be handled in solution or as part of a substrate whenever possible to minimize risk of inhalation. Whenever possible, work with nanoparticles should be handled within a containment device such as a fabricated bench-top enclosure, chemical fume hood or fully exhausted biosafety cabinet (Class II, Type B2). Recirculating biosafety cabinets are not permitted to be used with nanomaterials (Type A cabinets). Laboratory personnel should wear the appropriate respiratory protection (P-100 HEPA filtration) when working with nanoparticles outside of primary containment devices. Individuals wearing P-100 respiratory protection must be enrolled in the University Respiratory Protection Program.

Dermal

Available data are limited and often conflict; skin cannot be ruled out as a potential route of exposure

- Several studies show little to no penetration of nanoscale oxides beyond surface skin layers
- Polysaccharide and metal nanoparticles have been shown to penetrate flexed, damaged or diseased skin
- Quantum dots were found to penetrate intact pig skin within 8-24 hours at occupationally relevant doses

Various nanoparticles have been shown to

- Inhibit cell proliferation (iron oxide, nanotubes, TiO_2, silver)
- Affect cell morphology (silver, nanotubes)
- Initiate irritation response (quantum dots, nanotubes)
- Damage cell membrane (fullerenes)
- Induce DNA damage (cobalt chrome alloy)

Researchers are required to wear gloves (latex or nitrile) during all handling of nanoparticles and nanomaterials. Researchers are required to wear disposable Tyvek laboratory coats or cloth laboratory coats with disposable Tyvek or vinyl sleeves during all handling of nanoparticles and nanomaterials. Laboratory Attire Guidelines specified in the University Laboratory Safety Manual must also be followed. Consult OEHS for Guidelines.

Ingestion

Ingestion is a viable route of exposure; nanoparticles can translocate throughout the body

- Ingestion may occur after inhalation exposure when mucus is brought up the respiratory tract and swallowed
- Poor work practice can result in hand-to-mouth transfer
- Ingested nanoparticles do translocate to other organ systems. Single walled carbon nanotubes (SWCNT) delivered into gut for treating Alzheimer's disease was found in liver, brain and heart. Ingestion of colloidal silver can result in permanent discoloration of skin, nails and eyes
- Various nanoparticles have been shown to
  - Slightly damage liver (silver)
  - Trigger immune response in intestinal dendritic cells (TiO_2 and SiO_2)
  - Be cytotoxic to human intestinal cells (TiO_2, SiO_2 and ZnO)
  - Damage DNA of human intestinal cells (ZnO)
  - Be genotoxic to liver and lungs after oral administration (C_{60} and single-walled nanotubes (SWNT))

Eating, drinking, applying cosmetics, handling contact lenses is not permitted in the laboratory per University Guidelines. Laboratory personnel should remove PPE when work with nanoparticles is completed and wash their hands.

Injection

Nanoparticles can be introduced to the body via a needlestick. Standard precautions should be followed when utilizing sharps with nanoparticles or nanomaterials

Current Occupational Exposure Limits for Nanomaterials

Few occupational exposure limits exist specifically for nanomaterials. Certain nanoparticles may be more hazardous than larger particles of the same substance. Therefore, existing occupational exposure limits for a substance may not provide adequate protection from nanoparticles of that substance. However, some specific exposure limits already exist. For example:

- OSHA recommends that worker exposure to respirable carbon nanotubes (CNT) and carbon nanofibers not exceed 7.0 micrograms per cubic meter (µg/m3) in an 8-hour time-weighted average, based on the National Institute for Occupational Safety and Health (NIOSH) proposed Recommended Exposure Limit (REL). However, because a risk of adverse lung effects may occur even below the 7 $\mu g/m^3$ CNT REL, NIOSH further recommends reducing airborne levels of nanoscale carbon to as low as possible. In an April, 2013 Current Intelligence Bulletin (CIB) OSHA, recommends that exposures to carbon nanotubes and carbon nanofibers be kept below the recommended exposure limit of 1 µg/m3 of repairable elemental carbon as an eight-hour TWA.

- OSHA recommends that worker exposure to nanoscale particles of TiO2 not exceed NIOSH's 0.3 milligrams per cubic meter (mg/m3) REL. By contrast, NIOSH's REL for fine-sized TiO2 (particle size greater than 100 nm) is 2.4 mg/m3.
- NIOSH's REL for carbon black is 3.5 mg/m^3, and OSHA's permissible exposure limit for respirable synthetic graphite is 5 mg/m^3.
- Because exposure limits for other nanomaterials do not exist yet, employers should minimize worker exposure by using the hazard control measures and best practices identified below and in the references noted under "Resources."

The new CIB is available at http://www.cdc.gov/niosh/docs/2013-145/.

Assessing Worker Exposures to Nanomaterials

Employers should assess worker exposure to nanomaterials to identify the control measures needed and determine if the controls used are effective in reducing exposures by:

- Identifying and describing processes and job tasks where workers may be exposed to nanomaterials;
- Determining the physical state of the nanomaterials such as dust, powder, spray, or droplets;
- Determining routes of exposure (e.g., inhalation, skin contact or ingestion) of particulates, slurries, suspensions or solutions of nanomaterials;
- Identifying the most appropriate sampling method to determine the quantities, airborne concentrations, durations, and frequencies of worker exposures to nanomaterials; and
- Determining what additional controls may be needed based on the exposure assessment results and evaluating the effectiveness of controls already in place. Employers should adopt the most effective controls available to limit worker exposure.

Exposure Monitoring

Traditional bulk air sampling NIOSH/OSHA methods that measure mass per unit volume of air (mg/m^3, or as ppmv) will provide very limited information about the airborne concentrations of NMs. Real time particle counters (optical and condensation particle counters) that measure count per unit volume (mg/m3) are preferred for monitoring the airborne NPs. (TSI 8529 DustTrak™ Aerosol Monitor Measures real time concentration from 0.001 – 100 mg/m^3). Electron scanning microscopy, transmission electron microscopy and atomic force spectroscopy analyses of wipe samples are preferred to evaluate the surface contamination and particle characterization.

Methods Employers Can Use to Reduce Worker Exposure to Nanomaterials

Because the research and use of nanomaterials continues to expand and information about potential health effects and exposure limits for these nanomaterials is still being developed, employers should use a combination of the following measures and best practices to control potential exposures:

Engineering Controls

- Work with nanomaterials in ventilated enclosures (e.g., glove box, laboratory hood, process chamber) equipped with high-efficiency particulate air (HEPA) filters.

- Where operations cannot be enclosed, provide local exhaust ventilation (e.g., capture hood, enclosing hood) equipped with HEPA filters and designed to capture the contaminant at the point of generation or release.
- General recommendations for HEPA filtration of the exhausted air are given below.

Recommendation for HIPA Filtration for Nano hazards form Chemical Fume Hoods Or Local Capture Enclosure hoods			
	NM Toxicity Levels		
	Low	**Medium**	**High or Toxicity is Unknown**
Low	Not Required	Not Required	**Not Required**
Medium	**Not Required**	Recommended	**Required**
High	**Recommended**	**Required**	**Required**

Administrative Controls

- Provide handwashing facilities and information that encourages the use of good hygiene practices.
- Establish procedures to address cleanup of nanomaterial spills and decontamination of surfaces to minimize worker exposure. For example, prohibit dry sweeping or use of compressed air for cleanup of dusts containing nanomaterials, use wet wiping, sticky mats and vacuum cleaners equipped with HEPA filters.

Personal Protective Equipment (PPE)

- Provide workers with appropriate personal protective equipment such as respirators, gloves and protective clothing.

Medical Screening and Surveillance

- Make available medical screening and surveillance for workers exposed to nanomaterials if appropriate.
- Review medical surveillance requirements under OSHA standards (e.g., Cadmium, Respirator Protection).

General Guidelines for Handling Nanoparticles in University Laboratories

1. Principal Investigator (PI) is responsible for developing and reviewing safe work practices with research personnel working with nanomaterials or within the same laboratory area that nanomaterials are handled.
2. PI must create a Standard Operating Procedure (SOP) for research work involving nanomaterials. The SOP must be available to all research personnel working with nanomaterials or within the same laboratory area that nanomaterials are handled.
3. PI is responsible for maintaining MSDSs for all nanomaterials to be available and kept up to date within the laboratory in which nanomaterials are stored and used.
4. All manipulations of nanoparticles should occur in a dedicated chemical fume hood (annual certification of fume hood is required), hard ducted biological safety cabinet, glove bag, glove box or enclosed HEPA filtered glove box. Horizontal laminar flow

hoods (with air flow directed toward worker) are NOT permitted to be used with nanomaterials.

5. Work with nanoparticles outside of an exhausted enclosure require researchers to wear a NIOSH-approved P-100 particulate respirator (annual OEHS approved fit-test is required).
6. Nanoparticles should be handled while in solution or part of a substrate to minimize airborne release.
7. All containers (primary, secondary, and tertiary if applicable) should be labeled with the full name of the nanomaterials (avoid abbreviations and acronyms). "Nano" should be used in the chemical name.
8. Sealed, secondary containers should be utilized to transport nanomaterials between laboratories and buildings.
9. Every effort should be made to prevent the release of nanoparticles into the environment. OEHS recommends the use of a sticky mat at the exit of lab spaces where nanoparticles are handled.
10. Clean work areas at the end of each work shift (at a minimum) using a HEPA-filtered vacuum cleaner or wet wiping methods. Dry sweeping or air hoses should not be used to clean work areas.
11. Do not store or consume food or beverages in workplaces where nanomaterials are handled.
12. Prevent the inadvertent contamination of non-work areas (including take-home contamination) by showering and changing into clean clothes at the end of each workday

General Handling Requirements Based on Nanomaterial Risk Level (NRL)

NRL	Type of nanomaterial	Practices	Engineering Controls	PPEs
1	Polymer matrix	Standard Laboratory Practices including: 1.Lab Safety Plan should be updated with NRL defined 2.Labeling of storage containers of nanomaterials with both the chemical contents and the nanostructure form	Fume hood **or** biological safety cabinet (Class II Type A1, A2 vented via a thimble connection, B1 or B2)	Standard PPE (lab coat, gloves, safety glasses with side shields)
2	Liquid dispersion	1.NRL-1 practice plus: 2.Use secondary containment for containers that store nano-materials 3.Wipe contaminated areas with wet disposable wipes 4.Dispose of contaminated cleaning materials as segregated nanomaterial waste	Fume hood **or** biological safety cabinet (Class II Type A1, A2 vented via a thimble connection, B1 or B2) **or** approved vented enclosure (e.g., Flow Sciences vented balance safety enclosure [VBSE])	NRL-1 practice plus: Nitrile gloves, Safety goggles
3	Dry powders or aerosols	1.NRL-2 practice plus: 2.Vacuum with HEPA-equipped hand vacuum cleaner 3.Label work areas with "Caution Hazardous Nanoscale Materials in Use"	1. Fume hood **or** biological safety cabinet (Class II Type A1, A2 vented via a thimble connection, B1 or B2) **or** approved vented enclosure (e.g., Flow Sciences vented	1.NRL-2 practice plus: 2.N95 respirators are required if work operation must be done outside of containment

			balance safety enclosure [VBSE]). 2. HEPA filtered exhaust preferred for fume hoods containing particularly “dusty” operations.	
4	Dry Powders or aerosols of parent materials with known toxicity or hazards	1.NRL-3 practice plus: 2. Baseline medical evaluation or employees including physical exam, pulmonary function test (PFT) and routine blood work. 3. Access to the facility should be permitted only to persons who are knowledgeable about the hazards of the material and the specific control measures implemented to avoid exposures and/or environmental releases. These control measures should include work practices (SOPs), engineering controls, spill and emergency procedures, personal protective equipment, disposal procedures, and decontamination/clean up procedures. Department procedures should address the designation and posting of the laboratory, how access will be controlled, and any required entry and exit protocols.	1. Fume hood **or** biological safety cabinet (Class II Type B1 or B2) **or** glove box **or** approved vented enclosure (e.g., Flow Sciences vented balance safety enclosure [VBSE]). HEPA filtered exhaust with Bag-In/Bag-Out capability preferred for hoods, BSCs, and gloveboxes.	NRL-3 practice plus: Need determined and respirator selected with reference to the engineering controls in use and potential for aerosol generation

General Guidelines for Disposal of Nanoparticles and Associated Hazard Waste Solutions

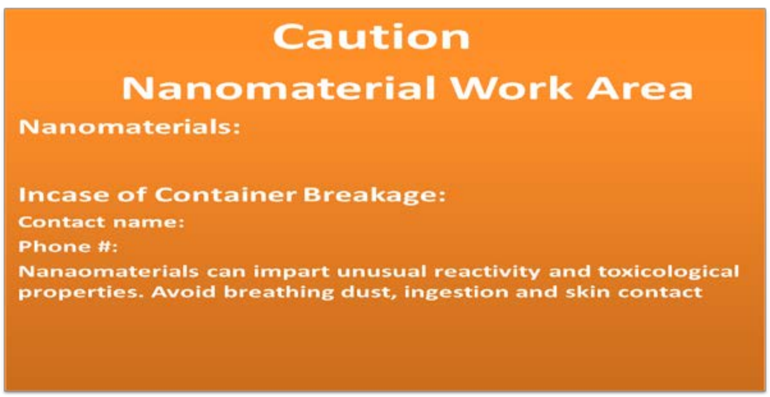
1. Since the toxicology and environmental fate of nanoparticles is still largely unknown, nanoparticle waste (solid material and liquids) should be managed through the University's Hazardous Waste program. Do not dispose of nanoparticle waste in regular trash or down the drain.
2. Waste container must be labeled at all times, no abbreviations on labels and must have the start date of waste collection.
3. Collect nanoparticle waste in a sealable container that remains closed except when adding the waste.
4. NM-containing wastes including NM dispersions must be disposed of through OEHS.
5. Sharps and needles should be disposed of as bio-hazardous waste.
6. Unused NM solids and NM dispersed solutions must be identified on the waste label.
7. If the nanoparticles are in solution, the solution should be managed accordingly (e.g., flammable solvents are handled as flammable waste materials).
8. Contact OEHS at 824- 2171 for further information about how to handle specific wastes.

General Guidelines for Nanomaterial Spill Clean-up

1. Secure area where spill occurred, restrict access to the area and notify others in the laboratory of the spill.
2. Dry nanomaterials should NOT be brushed or swept.
3. Spill cleanup should be done using a wet wipe method and/or HEPA-filtered vacuum.
4. Appropriate PPE (gloves, lab coat, and P-100 respirator) should be donned.
5. Spills of nanomaterials should be covered with a wet paper towel or bench paper.
6. Clean-up should begin from the outside of the spill and work inward.
7. All spill cleanup material should be collected in a leak proof plastic bag and should be disposed through OEHS.
8. Chemical Waste label should be placed on the plastic bag and "Nanomaterial Spill Cleanup Material" should be written on the label (along with specific chemical name).
9. In the event of a large spill, the spill area should be secured and OEHS should be contacted (824-2171).

Work Area Designation

1. NMs work should be performed within a designated area.
2. Work area must have warning signage as shown below.



Container labeling

1. Primary containers should be labeled for laboratory-generated NMs. Primary container information should include "Nano Chemical Name", solvent name (for dispersed solutions), concentration or quantity and contact person name.
2. At a minimum, reaction flasks and small storage vials, centrifuge tubes, etc., and secondary containers should include the material identity, researcher name, and date of preparation.

Transportation

1. Primary storage containers made of glass are preferred for the storage and transport of NMs (glass reduces electrostatic charges that can cause dry materials to become easily airborne when opening the container).

2. Sealed secondary containers should be used to transport NMs/solutions between labs.
3. The use of secondary containers made of shatter proof plastics is recommended to prevent the accidental breakage of primary glass containers during transport between labs.
4. If nanomaterials are required to be shipped off of the University campus via an external shipment company (Ex. UPS or FedEx) then applicable DOT shipping regulations must be followed. OEHS should be contacted to assist in the shipment of nanomaterials.
5. If nanomaterials are transported to off campus locations via a personal vehicle then applicable DOT packaging requirements must be followed.
6. The MSDS should be included in packages for NM shipment to outside institutions.

Training

Employers should check with manufacturers of chemicals and materials used in their workplace to determine if unbound engineered nanomaterials are present. The potential for nanomaterials to pose health or safety hazards is greater if the nanomaterials are easily dispersed (such as in powders, sprays, or droplets) or are not isolated or contained. In workplaces where workers will be exposed to nanomaterials, the employer should provide information and training to their workers. This information and training should include at least the following:

- Identification of nanomaterials the employer uses and the processes in which they are used;
- Results from any exposure assessments conducted at the work site;
- Identification of engineering and administrative controls and personal protective equipment (PPE) to reduce exposure to nanomaterials;
- The use and limitations of PPE; and
- Emergency measures to take in the event of a nanomaterial spill or release.

Additional Related Resources

NIOSH - Approaches to Safe Nanotechnology
Strategic Plan for NIOSH Nanotechnology Research and Guidance
IRSST - Best Practices Guide to Synthetic Nanoparticle Risk Management