**Interim Best Practices for Working with Nanoparticles**
**Center for High-Rate Nanomanufacturing**

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# 1 Introduction

## 1.1 Purpose of this Document

The NSF Nanoscale Science and Engineering Center for High-rate Nanomanufacturing (CHN) is committed to performing all of its activities in a manner that protects the health of workers, researchers and the environment. This document was written to provide interim best safety and health practices to students, staff and faculty of the CHN who work with nanoparticles. This contains "interim" best practices because the field of nanoparticle health and safety is rapidly evolving at this time; there is much that is not known about the toxicity of nanoparticles and the hazards of respiratory and dermal exposures, and there is no known safe threshold for such exposures to nanoparticles. It is expected that this document will be updated periodically – when this happens, the new version will be distributed to all CHN investigators.

This guidance document is applicable to laboratories that are working with nanoelements such as nanotubes and nanoparticles..

This document was prepared by the CHN Occupational and Environmental Health and Safety (OEHS) team, led by Prof. Michael Ellenbecker of the Toxics Use Reduction Institute, University of Massachusetts Lowell. Other team members include Prof. Jacqueline Isaacs, Northeastern University, head of the Societal Impacts thrust at CHN, Dhimiter Bello, assistant professor, UML, and Su-Jung (Candace) Tsai, postdoctoral researcher, UML. This document was written by Drs. Ellenbecker and Tsai.

## 1.2 Definitions

"Nanoparticles" are defined as dispersible particles having two or three dimensions greater than 1 nm and less than about 100 nm.

"Engineered nanoparticles" are defined as dispersible particles having two or three dimensions greater than 1 nm and less than about 100 nm that make use of properties unique to nanoscale forms of materials.[1] Common examples of engineered nanoparticles used at CHN are carbon nanotubes and fullerenes.

"Industrial nanoparticles" are defined as dispersible particles having two or three dimensions greater than 1 nm and less than about 100 nm that are either produced as a byproduct of industrial operations (*e.g.*, welding fume) or are nano-sized particles of a material that can also exist in larger sizes (*e.g.*, alumina particles).

The procedures described in this document are recommended for the handling of engineered nanoparticles and for industrial nanoparticles.

The work at CHN is on the "laboratory scale" – *i.e.*, work with substances in which the containers used for reactions, transfers, and other handling of substances are designed to be

[1] ASTM E2456-06, "Standard Terminology Relating to Nanotechnology.

easily and safely manipulated by one person. "Laboratory scale" excludes those workplaces whose function is to produce commercial quantities of materials.[2]

### 1.3 Limitations

- Information about the toxicity of nanoparticles, particle measurement methods, and exposure control techniques is changing rapidly. This document will be updated in an attempt to remain current, but it may not always reflect the latest information. Researchers should direct questions about these topics to the CHN EHS team.
- If any information or policies presented here contradict that of any university health and safety office, the policy of that office shall take precedence.
- Alternative methods to safely handle nanoparticles may be developed by CHN researchers, or be published in other official or peer reviewed publications. Researchers are encouraged to look for such alternative methods, and to bring them to the attention of the CHN EHS team.
- The work practices presented here assume that engineered nanoparticles **may** be toxic to humans, so that exposure must be minimized. If, in the future, toxicology and/or epidemiology demonstrates that a particular engineered nanoparticle is nontoxic, these work practices could be relaxed for that particular nanoparticle.

## 2 Basic Premises

At this time, relatively little is known about the potential toxicity of nanoparticles, especially engineered nanoparticles. Recent toxicology studies, however, suggest possible adverse health effects associated with inhalation and dermal exposure to engineered nanoparticles such as carbon nanotubes and fullerenes [1-5]. These studies utilized animals exposed at high doses; no human data exist.

Given the uncertainty as to the level of risk, CHN students, staff and faculty must take a precautionary approach to working with nanoparticles. The Precautionary Principle states that, when faced with scientific uncertainty, one should follow the path of precaution to minimize possible adverse outcomes. Applied to CHN, this means that we need to take reasonable steps to reduce our exposure to nanoparticles to the lowest possible level until the science tells us that exposure limits that will not pose undue risk.

The three possible routes of exposure to nanoparticles are through the inhalation of airborne nanoparticles, dermal exposure, and ingestion. These best practice guidelines are designed to help you minimize potential exposure through these three routes.

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[2] 29 CFR1910.1450(b)(2), *Occupational Exposures to Hazardous Chemicals in Laboratories. Definitions.*

## 3 Occupational Hygiene Resources Available to CHN Researchers

Each university in the CHN has an environmental health and safety (EHS) office. These offices have the responsibility for ensuring the health and safety of laboratory personnel on their respective campus and should be contacted whenever a question arises concerning health and safety in CHN laboratories. The point of contact for each university is:

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| Northeastern Univ.: | Jack Price | 617 373-2769 |
| UMass Lowell: | Rich Lemoine | 978 934-2619 |
| University of NH: | Alexis Sablock | 603 862-4761 |

In addition, the CHN occupational and environmental health and safety (OEHS) research team is available to work with you and your university health and safety office to investigate possible unsafe practices. The CHN OEHS should be viewed as a group with specialized knowledge concerning the issues of nanoparticle health and safety and is available to offer assistance to the university EHS offices. This team offers annual training to new students and investigators on the potential hazards of working with nanoparticles and is actively researching the health and safety aspects of working with nanoparticles, including the measurement of possible nanoparticle exposures in CHN labs. Please contact Dr. Ellenbecker, ellenbec@turi.org, for more information.

## 4 Routine R&D Laboratory Operations

### Basic Principles

Laboratory operations should be carried out in a manner that minimizes the risk of exposure to nanoparticles from inhalation or dermal contact. Certain basic principles will contribute to minimizing your risk.

- Nanomaterials in dry powder form pose the most risk for inhalation exposure and must be handled with care to minimize the generation of airborne dust and to minimize dermal contact.
- Nanomaterials suspended in a liquid present less risk for inhalation exposure than nanomaterials in dry powder form, but may present more risk from skin contact. Skin uptake of nanomaterials as dry powders and in solvents is poorly understood at this time. It is likely that skin uptake of nanoparticles may be enhanced significantly in compromised skin and/or in the presence of solvents!
- Nanomaterials incorporated into a solid matrix present the least risk for inhalation exposure due to their limited mobility. Although poorly understood at this time, there is circumstantial evidence to caution that certain nanomaterials incorporated into bulk solids may still pose some risk through skin contact, especially nanomaterials with immunological properties, which have some solubility in sebaceous fluids.

**Control Preferences**

1. Follow a graded approach in specifying controls. Operations involving easily dispersed dry nanomaterials deserve more attention and more stringent controls than those where the nanomaterials are imbedded in solid or liquid matrixes. Skin contact with liquids and solids containing nanoparticles should also be avoided.

2. Avoid manipulating nanomaterials in the open air in a “free particle” state. Preferably (1) keep them bound in a matrix, (2) suspended in a liquid, or (3) sealed in a container. The following precedence should be strived for whenever practicable:
    a. Fixed in a matrix
    b. Bound in a solution
    c. Free Particles

3. Follow the standard hierarchy of hazard controls for nanomaterials:
    a. Engineering controls
    b. Administrative (procedural) controls
    c. Personal protective equipment

4. Consider the hazardous properties of the precursor materials and processing chemicals as well as those (possibly unknown) of the resulting nanoparticle product. A university EHS professional can assist with this evaluation.

5. Carry out all manipulations of free nanoparticles in a chemical fume hood or glove box whenever possible. For larger processes that cannot fit in a fume hood or glove box (e.g., injection molding), control emissions from those processes with properly-designed local exhaust ventilation (see Section 4.3 below). If nanoparticles must be handled outside such a ventilation system, institute other appropriate engineering controls or wear appropriate respiratory protection and other personal protective equipment (PPE) as determined by an industrial hygiene review.

**Ventilation Design Principles**

All ventilation systems should be evaluated and approved by the university health and safety office. Under no circumstances should laboratory personnel design their own ventilation system and/or modify an existing system. The ventilation system should be maintained on a routine basis by the appropriate university maintenance personnel. Contact your EHS office if such maintenance is not occurring.

**Laboratory Fume Hoods**

Where practicable, carry out all manipulations of free engineered nanoparticles in a HEPA filtered powered-exhaust chemical fume hood or glove box. Examples include Class II Type B1 or B2 biological safety cabinets. If nanoparticles must be handled outside such a hood, institute other appropriate engineering controls or wear appropriate respiratory protection and other personal protective equipment (PPE) as determined by the Principle Investigator.

The effectiveness of a laboratory fume hood in protecting the user form chemical or nanoparticle exposure is dependent on the proper placement of the hood sash and the resulting face velocity into the hood. Each NSEC EHS office has a procedure for routinely monitoring laboratory fume hood performance and determining proper hood sash height to give good performance. Each fume hood should be clearly marked with the proper hood sash location; depending on the hood design, this could be a single location or a range of locations. It is extremely important that processes be carried out inside the hood with the sash at the single position or within the range of positions specified by the university EHS office. Experiments performed by the CHN OEHS research team have demonstrated that working with the sash either too low or too high can cause nanoparticles released inside the hood to escape from the hood and cause exposure to the researcher. In addition, equipment should be located at least 6 in. behind the sash, hood clutter should be minimized, and researchers should avoid making rapid or violent motions while working in the hood.

If process requirements require that these conditions cannot be met, contact your health and safety office for an evaluation of potential exposures.

Do not directly exhaust effluent (air) that is reasonably suspected to contain engineered nanoparticles. The exhaust air must be passed through a HEPA filter, since at this time it is the only air pollution control device known to control nanoparticles with high efficiency.

### Other Ventilation Systems

Some processes that require the manipulation of nanoparticles are too large to fit in a standard laboratory fume hood (e.g., compounding with an extruder in Plastics Engineering at UMass Lowell). In these cases, a local exhaust ventilation (LEV) system can usually be designed to capture the emissions from the process. It is *extremely important* that the LEV system be designed by a competent professional. Your health and safety office, along with CHN OEHS, can design a proper system. It is also important that the system be used properly and that it not be modified without consultation with the H&S office.

### Administrative Controls

### Housekeeping

Practice good housekeeping in laboratories where nanomaterials are handled. Clean all working surfaces potentially contaminated with nanoparticles (i.e., benches, glassware, apparatus, exhaust hoods, support equipment) at the end of each day using a HEPA[3] vacuum pickup and/or wet wiping methods. Each CHN lab and EHS office has been or will be furnished with the proper

[3] HEPA stands for High Efficiency Particulate Air filter. Shop vacuums equipped with HEPA filters will remove 100% of the nanoparticles in the vacuumed air, whereas many of those particles will pass right through a standard shop vacuum and contaminate the lab air.

HEPA vacuum. The HEPA vacuums should be labeled "For Use with Nanoparticles Only" and used only for this purpose. Do not dry sweep or use compressed air. Dispose of used cleaning materials in accordance with the hazardous-waste procedures described in Section 5.2 of this document.

**Work Practices**

- Transfer nanomaterials samples between workstations (such as exhaust hoods, glove boxes, furnaces) in closed, labeled containers.
- Do not allow nanoparticles or nanoparticle-containing materials to contact the skin.
- If nanoparticle powders must be handled outside a fume- or exhausted laminar flow-hood, use appropriate respiratory protection.
- Vacuum up dry nanoparticles only if the vacuum cleaner has a tested and certified HEPA filter.
- As an alternative to HEPA-vacuuming lab benchtops, benchtop protective covering material (e.g., Fisherbrand® Absorbant Surface Liner) can be used; this material should be disposed of in accordance with Section 5.2 of this document at the end of any day when nanomaterials were used on it.
- Handle nanomaterial-bearing waste (see definition below) according to Section 5.2 of this document.

**Clothing and Personal Protective Equipment**

- Wear appropriate personal-protective equipment on a precautionary basis whenever the failure of a single control, including an engineered control, could entail a significant risk of exposure to researchers or support personnel.
- Wear clothing appropriate for a wet-chemistry laboratory including

  Closed-toed shoes made of a low permeability material. (Disposable over-the- shoe booties may be necessary to prevent tracking nanomaterials from the laboratory)

  Long pants without cuffs

  A long sleeved shirt

  Disposable laboratory coats. These coats should be handled in accordance with Section 5.2 of this procedure. If non-disposable laboratory coats are preferred, they should remain in the laboratory/change out area to prevent nanoparticles from being transported into common areas. The coats should be placed in closed bags before being taken out of the laboratory for cleaning in a central approved location.
- Wear latex or nitrile gloves when handling nanopowders and nanoparticles in liquids.

  Exposure to nanomaterials is not known to have "good warning properties" so gloves should be changed frequently.

The contaminated gloves should be kept in a closed plastic bag in the work area until disposal. The resulting waste should be managed in accordance with Section 5.2 of this procedure.

Outer gloves made of other material, such as cotton, may be used for protection when handling articles wherein the nanomaterials are in bound form.

- Safety glasses, and/or face shields, should be worn appropriate for the level of hazard. A face shield alone is not sufficient protection against unbound dry materials.
- The appropriate respirator and cartridge combination, based on an EHS analysis, should be worn when deemed necessary by the safety assessment. Personnel should receive medical clearance by medical doctor before being fitted with a respirator. If a respirator is indicated, it should be at a minimum a half-mask, P-100 cartridge-type respirator that has been properly fitted to the worker.
- Personnel not required to wear a respirator may do so at their discretion. In this case, disposable respirators (also called dust masks – surgical masks should be avoided) with at least an N95 filter rating are acceptable.
- Each university has their own respirator program that is more specific than these general recommendations – please contact your EHS office whenever respirator use is contemplated.

## 5 Management of Nanomaterials

### General

Engineered nanomaterials must be managed as a hazardous material. The requirements of this section apply only to engineered nanomaterials, not industrial nanomaterials such as nanoclay, etc.

The following label should be placed on all containers containing engineered nanomaterials:

**CAUTION**

**Nanomaterials Sample**
**Consising of <u>(Technical Description Here)</u>**
**Contact: <u>(POC)</u>**
**at <u>(Contact number)</u>**
**in Case of Container Breakage.**

Labels can be obtained from your EH&S office.

### Waste Streams

#### 5.2.1 Definitions

The following waste management guidance applies to engineered nanomaterial-bearing waste streams consisting of

- Pure engineered nanomaterials (e.g., carbon nanotubes)
- Items contaminated with engineered nanomaterials (e.g., wipes/PPE)
- Liquid matrices containing nanomaterials (e.g., acid containing carbon nanotubes)
- Solid matrices with engineered nanomaterials that are friable or have a nanostructure loosely attached to the surface such that they can reasonably be expected to break free or leach out when in contact with air or water, or when subjected to reasonably foreseeable mechanical forces.

The guidance does not apply to nanomaterials embedded in a solid matrix that cannot reasonably be expected to break free or leach out when they contact air or water.

### Management of Nanomaterial-containing Waste Streams

- Do not put engineered nanomaterial waste in the regular trash or dump it down the drain
- All nanomaterial waste, as defined above, should be collected in labeled, enclosed hazardous waste containers with secure caps or covers. The label should include a description of the waste and the words "*contains nanomaterials*".
- Collect paper, wipes, PPE and other items with loose contamination in a plastic bag or other sealable container and store it in a fume hood until it is full, then double-bag it, label it, securely tie or seal it, and dispose of it according to these procedures.
- Nanomaterial hazardous waste containers shall be collected and disposed of as hazardous waste following the standard procedures of your university.

## 6 Management of Nanomaterial Spills

### Equipment

Each CHN lab must have a nanoparticle spill kit readily available to respond to spills. At a minimum, this kit should contain:

- Barricade tape
- Latex or nitrile gloves
- Disposable N95 respirators
- Adsorbant material
- Wipes
- Sealable plastic bags
- Walk-off mat

**Access Control**

- Determine the extent of the area reasonably expected to have been affected, and demarcate it with barricade tape or use another reliable means of restricting entry into the area.
- Assess the extent of the spill. Significant spills are defined as those of more than a few grams of nanoparticles.
- To clean up significant spills, contact the EH&S office, and restrict entry into the area to personnel from that organization.
- Smaller spills can be cleaned up by trained personnel from the lab using the following cleanup procedures.

**Dry Materials**

- Position a walk-off mat (e.g., Tacki-Mat®) where clean-up personnel will exit the access-controlled area.
- Do not dry sweep spilled accumulations of dry nanomaterials. Small quantities of dry materials (*i.e.*, gram quantities) can be cleaned up with wet wipes. Dispose of the wipes as hazardous waste, as described above. Significant spills should be vacuumed, under direction of the EH&S office. Use only HEPA-filtered vacuum cleaners to clean up nanoparticles.
- Ensure that the functioning of the HEPA filters was properly tested as frequently as the manufacturer's recommends. HEPA vacuums for nanomaterials should be dedicated and labeled "For Use with Nanomaterials Only". Used HEPA filters must be appropriately characterized, collected, and disposed of as hazardous or potentially hazardous waste based on the material involved.

**Liquids**

Employ normal hazmat response based on the spilled material's known hazards. The following are additional considerations to mitigate nanomaterials left behind once the liquids have been removed:

- Position an absorbent walk-off mat where the clean-up personnel will exit the access controlled area.
- Place barriers that will minimize air currents across the surface affected by the spill.
- Use a HEPA-filtered vacuum dedicated to the clean-up of nanomaterials.
- Treat all materials used to clean up the spill (absorbent mats, absorbent material, wipes etc) as hazardous waste based on the material involved.

**Wastes**

- Manage all debris resulting from the clean up of a spill as though it contains sufficient nanomaterials to be managed in accordance with Section 5 of this procedure.

**References**

[1] J. Ferin, G. Oberdörster, S.C. Soderholm, R. Gelein, Pulmonary tissue access of ultrafine particles, J. Aerosol Med.-Deposit. Clear. Effects Lung 4(1) (1991) 57-68.

[2] Q. Zhang, Y. Kusaka, K. Donaldson, Comparative pulmonary responses caused by exposure to standard cobalt and ultrafine cobalt, J. Occup. Health. 42 (2000) 179-184.

[3] R.K. Wolff, R.F. Henderson, A.F. Eidson, J.A. Pickrell, S.J. Rothenberg, F.F. Hahn, Toxicity of gallium oxide particles following a 4-week inhalation exposure, J. Appl. Toxicol. 8(3) (1988) 191-199.

[4] D. B. Warheit, Nanoparticles: health impacts? Materials today (2004) 32-35.

[5] L C Renwick, D Brown, A Clouter, K Donaldson, Increased inflammation and altered macrophage chemotatic responses caused by two ultrafine particle types, University of Edinburgh, UK, Occup Environ Med 61 (2004) 442-447.