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Nanomaterials Safety Manual

E. Asmatulu, F. Plummer and G. Miller
Wichita State University
Department of Environmental Health and Safety
Wichita, KS 67260

Safety and Environmental considerations are important part of our daily lives, not only for our individual protection, but for the protection of others and the environment as well. In order to maintain a high level of knowledge and responsiveness, each employee and faculty member is issued a copy of this manual. This safety manual is the guiding document of the University Safety Program. Each employee, student and faculty member is responsible for following/obeying to the rules included herein. Student workers are especially subject to accidents and environmental mistakes, and must be trained and guided by knowledgeable faculty and staff. Questions about the content of the manual should be directed to your supervisor or Environmental Health and Safety representatives.

This informational booklet is proposed to provide a general overview of a particular safety related topic. This publication does not itself alter compliance responsibilities, which are set forth in OSHA standards themselves, Department of Environmental Health and Safety at Wichita State University.

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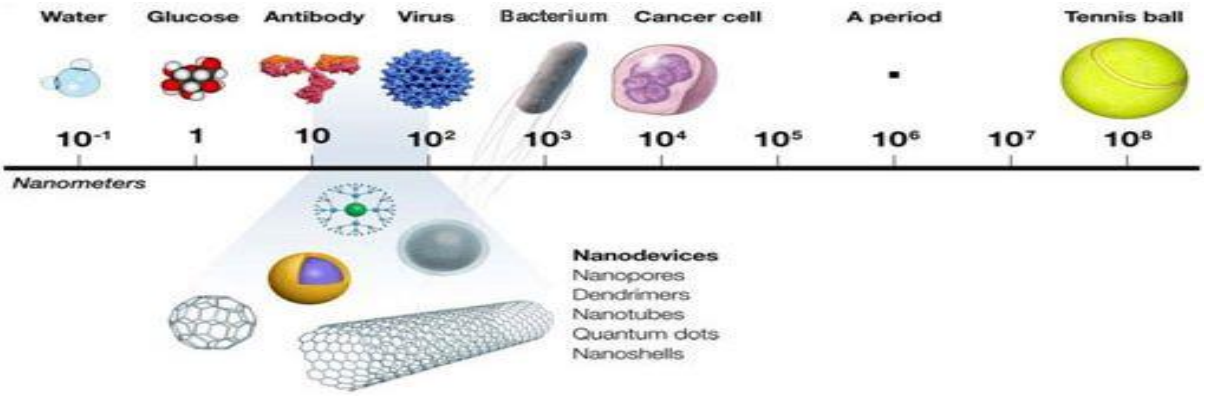
1. Introduction

Nanotechnology is the manipulation of matter at an atomic, molecular, and/or supramolecular scale. Nanotechnology as the manipulation of matter with at least one dimension sized from 1 to 100 nanometers (1 nm = 10 Angstrom). At these length scales, materials begin to exhibit unique physical, chemical, physicochemical and biological properties that affect overall behavior of the materials.



Source: http://networksandservers.blogspot.com/2011/01/nanotechnology.html

Figure 1: A diagram showing various microscopic organisms in nanoscales and a list of nanodevices.

Nanomaterials are increasingly used in a wide range of applications in science, technology, and medicine. The rapid development of a multitude of nanoparticle applications without clear guidelines necessitates assessing possible implications, assuring safe and sustainable handling of nanoparticles [1].

2. Nanoparticle Types

Nanoparticles fall into three major types: naturally occurring, incidental, engineered [2].

2.1 Naturally Occurring

Examples of naturally occurring nanoparticles include; sea spray, mineral composites, volcanic ash, viruses [2].

2.2 Incidental Nanoparticles

A result of man-made industrial processes may cause some diseases.

Table 1: Possible health effects cause by incidental nanoparticles [2]

Incidental nanoparticles	Possible health effects
Cooking smoke	Pneumonia, chronic respiratory disease and even lung cancer.
Diesel exhaust	Cancer and respiratory disease.
Welding fumes	Metal fume fever, infertility, benign pneumoconiosis.
Industrial effluents	Asthma, atherosclerosis, chronic obstructive pulmonary disease.
Sandblasting	Silicosis

2.3 Engineered Nanoparticles

Engineered nanoparticles comprise of any manufactured particles with nanoscale dimensions. Examples include; metals, quantum dots, buckyballs/nanotubes, sunscreen pigments, nanocapsules [2].

2.3.1 Dimensions

As shape, or morphology, of nanoparticles plays an important role in their toxicity, it is useful to classify them based on their number of dimensions. This is a generalization of the concept of aspect ratio [1]. Classification is based on the number of dimensions, which are not confined to the nanoscale range (<100 nm).

1D nanomaterials: Materials with one dimension in the nanometer scale are typically thin films, coatings, multilayer, etc.

2D nanomaterials: Two-dimensional nanomaterials have two dimensions in the nanometer scale. These include Tubes, fibers, wires, platelets, etc

3D nanomaterials: Materials that are nanoscaled in all three dimensions are considered 3D nanomaterials. These include particles, quantum dots, hollow spheres, etc.

2.3.2 Morphology

Morphological characteristics to be taken into account are: flatness, sphericity, and aspect ratio. A general classification exists between high- and low-aspect ratio particles (Figure 2). High aspect ratio nanoparticles include nanotubes and nanowires, with various shapes, such as helices, zigzags, belts, or perhaps nanowires with diameter that varies with length. Small-aspect ratio morphologies include spherical, oval, cubic, prism, helical, or pillar. Collections of many particles exist as powders, suspension, or colloids.

2.3.3 Phase Compositions

Nanoparticles can be composed of a single constituent material or be a composite of several materials.

Table 2: The phase compositions of nanoparticles

Phase compositions	Examples
Single-phase solids	Crystalline, amorphous particles and layers, etc.
Multi-phase solids	Matrix composites, coated particles, etc.
Multi-phase systems	Colloids, aerogels, ferrofluids, etc.

2.3.4 Nanoparticle Uniformity and Agglomeration

Based on their chemistry and electro-magnetic properties, nanoparticles can exist as dispersed aerosols, as suspensions/colloids, or in an agglomerate state (Figure 2). For example, magnetic nanoparticles tend to cluster, forming an agglomerate state, unless their surfaces are coated with a non-magnetic material. In an agglomerate state, nanoparticles may behave as larger particles, depending on the size of the agglomerate. Hence, it is evident that nanoparticle agglomeration, size and surface reactivity, along with shape and size, must be taken into account when deciding considering health and environmental regulation of new materials[2].

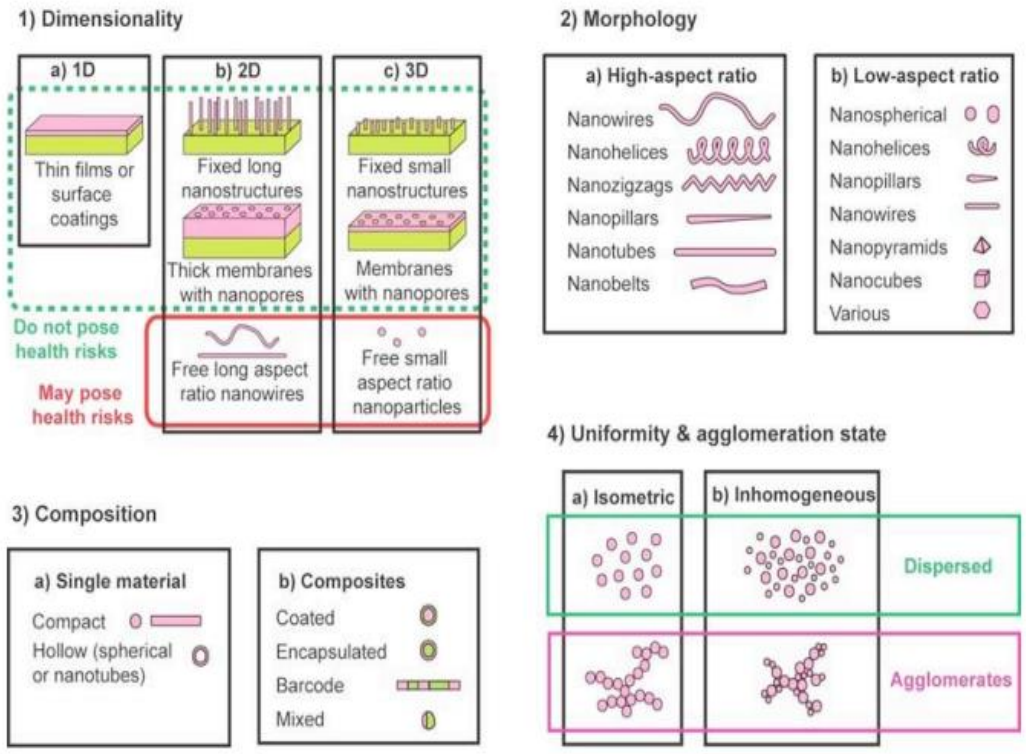


Figure 2: Classification of nanostructured materials [2].

3. Nanoproducts

Woodrow Wilson Center's Project on Emerging Nanotechnologies (PEN) is a foundation which analyzes the nano consumer products. The PEN's Consumer Products Inventory (CPI) contains a relatively large and complete nanoproduct list. As of October 2013, the nanotechnology consumer products inventory contains 1628 products or product lines.

The consumer products have a wide range of applications, such as clothing, sports goods, personal care products, medicine, as well as contributing to faster and stronger cars and planes, more powerful computers and satellites, better micro and nanochips, and long-lasting batteries [3].

Exposing nanomaterials may occur during the production, experimenting, transortion and also using nanoproducts. An example of exposure by nanoproduct usage includes aerosol sprays, sunscreen body lotion or taking supplements which contains nanomaterials.

4. Mechanisms Behind Toxicity of Nanomaterials

4.1 Surface Chemistry

A small aggregate or single particle is presumed to be more toxic than an aggregate of nanosized particle as the relative surface area could change, determining whether the material has a good wetting characteristic or has a surface characteristic that catalyzes specific chemical reactions or remains passive and allows fibrous tissue to grow on its surface.

4.2 Particle Size

A reduction in the size of nano-sized particles increases the particle surface area. Additional chemical molecules may attach to this surface, enhancing the reactivity and increasing toxic effects. Small nanoparticles (<100 nm) cause adverse respiratory health effects, typically causing more inflammation than larger particles made from the same material [2].

4.3 Surface Charges

High surface charge densities may cause higher cytotoxic effects than those with low charge densities. High surface charges react more intensely with cell membranes, creating additional damage to the cell [2].

As an electrostatic property, **Zeta potential** measures the colloidal stability of nanomaterial samples in suspension. This is closely related to the particle surface charge and will heavily influence aggregation state. Through a low zeta potential colloids will tend to aggregate. The

resulting aggregation may be observed through particle size and concentration measurements due to the increased size of aggregates, and the reduction in concentration of individual primary particles through aggregation [4].

4.4 Surface Area

Compared to micro particles, nanoparticles have a very large surface area and high particle number per unit mass. As the material in nanoparticulate form presents a much larger surface area for chemical reactions, reactivity is enhanced. According to Driscoll, 1996 and Oberdörster, 2001, surface area is the metric that is highly correlated with particles induced adverse health effects [5].

Oxidative stress: Most of the nanoparticles produce free radicals which cause oxidative stress. Biological oxidative stress may cause inflammation, cell destruction, and genotoxicity. The particle surface of the free radicals can activate the redox cycle and cause particle toxicity.

As a particle size decreases the proportion of constituent atoms or molecules displayed on the surface increases. This increasing proportion of surface molecules represents the specific surface area of a particle. Through an increasing specific surface area the proportion of constituent molecules able to interact with the surrounding environment also increases. This represents an increased opportunity for chemical reactivity of a particle and therefore the production of Reactive Oxygen Species (ROS) and free radicals. ROS induced oxidative stress has been indicated as the underlying mechanism of nanomaterial toxicity with the potential to cause DNA damage, cytotoxicity, cell membrane disruption and interfere with cell signalling. ROS has also been indicated in secondary toxic effects of nanomaterials including oxidation of proteins and release of hazardous constituents [4].

5. Exposure Factors

5.1 Concentration

Small concentrations of nanoparticles with size smaller than 100 nm can have a higher probability of translocating to the circulatory system and organs (and produce damage) than high concentrations of the same particles. The measure that correlates with the effects is the surface area and not the mass dose.

5.2 Duration

High concentrations over a long duration are more likely to produce adverse health effects than the same or lower concentration over a shorter exposure period. Patients who have higher concentrations and longer durations of exposure result in greater doses to the victim and will more likely have harmful effects [6].

5.3 Frequency

The frequency of the exposure affects the concentration at the target site—can build up to a steady level-why some medications are taken three times a day vs. once a day to give the wanted effect [7].

6. Nanoparticle Hazards

Adverse effects of nanoparticles on human health depend on individual factors such as genetics and existing disease, as well as exposure, and nanoparticle chemistry, size, shape, agglomeration state, and electromagnetic properties. The key to understanding the toxicity of nanoparticles is that their minute sizes are smaller than cells and cellular organelles, which allows them to penetrate these basic biological structures, disrupting their normal functions [1].

Nanoparticle exposure during manufacturing and use may occur through:

- Inhalation
- Dermal
- Ingestion

6.1 Inhalation Hazards

Inhalation of airborne nanoparticles may be deposited in the respiratory tract and also enter the blood stream and translocate to other organs. Some nanoparticles can induce cancers, including mesothelioma and also may cause rapid and persistent pulmonary fibrosis, cardiovascular dysfunction, and can migrate along the olfactory nerve into the brain [2].

6.2 Dermal Hazards

Human skin is composed of three distinct layers: the epidermis, dermis, and fat layer. Several studies indicated as a result of the thick skin layers, nanoparticles show little to no penetration of nanoscale oxides. However, various nanoparticles have been shown to affect the dermal:

- Metal nanoparticles have been shown to penetrate damaged or diseased skin.
- Iron oxide, nanotubes, TiO_2, and silver have been shown to inhibit cell proliferation.
- Nanotubes affect cell morphology.
- Fullerenes damage cell membrane.

6.3 Ingestion Hazards

Ingestion occurs after inhalation exposure when mucus is brought up the respiratory tract and swallowed. Ingested nanoparticles may travel to other organ systems (e.g. liver, brain, and heart).

Various hazard data show that ingestion of nanoparticles can cause adverse health effects:

- Ingestion of colloidal silver can result in permanent discoloration of skin, nails and eyes.
- Ingestion of Zinc Oxide can damage DNA of human intestinal cells.

Control measures must be assessed for labs that use nanomaterial. Monitoring particle distribution in the work and laboratory areas is encouraged. Furthermore, biological monitoring measures:

- Contaminants
- Metabolites or enzymes in the blood
- Urine
- Exhaled breath

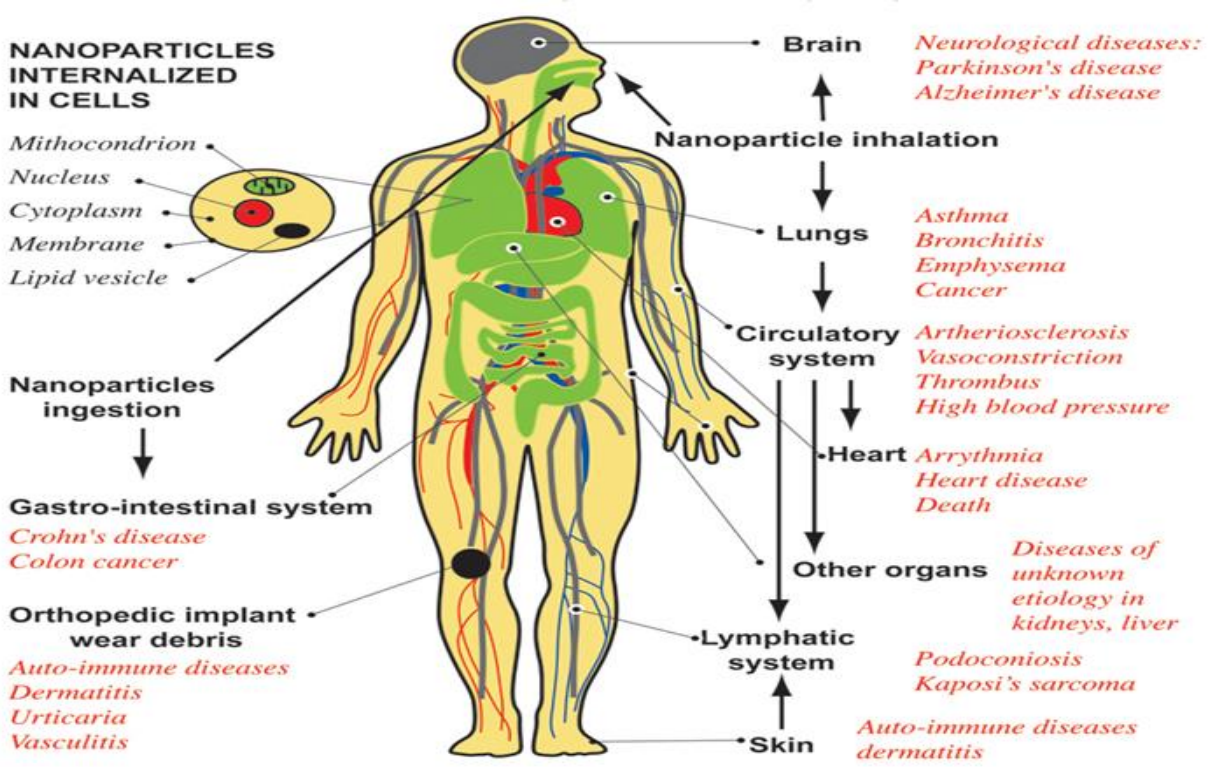


Figure 3: Diseases associated to nanoparticle exposure [1].

7. Best Practices for Handling Nanomaterials in Laboratories

7.1 Preplan Ahead of Time

Preplan the experiments and determine equipment and procedures needed to factor in all the items discussed below.

- These include equipment and procedures to prevent inhalation, skin or ingestion exposures, to prevent laboratory contamination, and to properly dispose of all nanomaterial waste.
- Have appropriate spill materials on hand before beginning your work.

- Equipment setup may require additional exhaust ventilation and installation or the use of respirators. All additions to or changes in exhaust ventilation must be approved by the EHS Office. All users of respirators must be fit tested to insure they are wearing the proper size. Contact the EHS Office for ventilation changes and respirator fit testing.

7.2 Defining Toxicity of Nanoparticles

- Be aware that many Safety Data Sheets (SDSs) currently shipped with nanomaterials refer to the bulk material toxicity information, which is inappropriate for the nanomaterial. Consider, but do not unquestioningly rely on, chemical hazard information for bulk/raw materials when developing controls for nanomaterials and any new information specific to the material at the scale being used [8-10].
- If no information is available for your materials or the toxicity information is limited or uncertain, handle the material as if it is toxic.
- The best place to keep up to date is the International Council on Nanomaterials (ICON) database which collects toxicity and environmental information by nanoparticle type (link is available on http://icon.rice.edu/report.cfm). Searches can be run on a specific nanomaterial for a particular time period, so only the most recent references are searched. You can also search Pub Med but the search results will be much broader than ICON [8].

7.3 Use Risk Assessment

Risk assessment is the determination of quantitative or qualitative value of risk related to an actual situation

- Base your risk assessment on the type of nanomaterial (composition, shape, size, surface area, physical status) [9].
- The Nanomaterial Risk Level (NRL) summary chart (Table 3) is a helpful tool to use for your initial risk assessment.
- Reference Safety Data Sheet (SDS).
- Utilize the proper engineering controls.
- Utilize personal protective equipment (PPE).
- Institute work practice controls (Administrative Control).
- Contact EHS if assistance is needed

Table 3: Summary of Recommended Nanomaterial Risk Levels (NRL) [8]

Summary of Recommended Nanomaterial Risk Levels (NRL)				
NRL	**Type of Nanomaterial**	**Practices**	**Engineering Controls**	**Personal Protective Equipment (PPE)**
1	Polymer matrix	Standard Laboratory Practices including: Lab Safety Plan should be updated with NRL defined 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	NRL-1 practice plus: Use secondary containment for containers that store nanomaterials Wipe contaminated areas with wet disposable wipes 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	NRL-2 practice plus: Vacuum with HEPA-equipped hand vacuum cleaner Label work areas with "Caution Hazardous Nanoscale Materials in Use"	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]). HEPA filtered exhaust preferred for fume hoods containing particularly "dusty" operations.	NRL-2 practice plus: N95 respirators are required if work operation must be done outside of containment

Summary of Recommended Nanomaterial Risk Levels (NRL)				
NRL	**Type of Nanomaterial**	**Practices**	**Engineering Controls**	**Personal Protective Equipment (PPE)**
4	Dry Powders or aerosols of parent materials with known toxicity or hazards	NRL-3 practice plus: Baseline medical evaluation or employees including physical exam, pulmonary function test (PFT) and routine blood work. 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.	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

7.4 Exposure and Safety Assessment

Methods for controlling potential exposures to airborne and liquid materials in the workplace include **process design** and **engineering controls** such as containment and ventilation systems, work practices, administrative actions, and personal protective equipment. The adequacy of exposure controls for exposure to free nanomaterials is greater than for embedded nanomaterials.

7.5 Prevent Inhalation Exposure during All Handling of Nanomaterials

All free particulate nanomaterials should be worked with in exhausted enclosures which may include fume hoods, glove boxes, Class II Type A2, B1 or B2 biosafety cabinets, reactors and furnaces. Procedures involving manipulation of nanomaterials as free particles should be carefully conducted so that no release into the laboratory air occurs. Manipulation of free

nanoparticulate on the lab bench should be avoided. Work with suspensions of nanoparticles that are subjected to processes that generate aerosols should be performed in exhausted enclosures.
Fume Hoods: When using a fume hood to contain dust or aerosols of nanomaterials, follow good fume hood use practices such as working 6" back from sash, working with sash below the chin, removing arms slowly from hoods to prevent dragging out contaminants, and not blocking the lower back slot with equipment.
Biosafety Cabinets (BSCs): Only Class II type A2, B1 or B2 biosafety cabinets which are exhausted into the building ventilation system may be used for nanomaterials work. BSCs that recirculate into the room may not be used. There is recirculation of air inside type A2 and B1 cabinets, so care should be taken not to perform extremely dusty processes in these cabinets as the internal fans of the BSC are not explosion proof. The air in the type B2 cabinet is 100% exhausted and standard amounts of nanomaterials and solvents may be used in this type of enclosure. The EHS Office should be consulted when considering a biosafety cabinet for control of nanomaterials.
Ventilation for furnaces and reactors: should be provided to exhaust gasses generated by this equipment. If possible, the exhaust gasses should be run through a liquid filled bubbler to catch particulate before it enters the building ventilation system. Parts removed from reactors or furnaces for cleaning that may be contaminated with nanomaterial residue should be repaired or cleaned in a fume hood or other type of exhausted enclosure.
Ventilation for large equipment or engineering processes: Equipment that is too large to be enclosed in a fume hood can be set up such that specially designed local exhaust ventilation can capture contaminants at points where emission is possible. Also custom enclosures can also be designed by local vendors to contain potential emissions. Call the EHS Office for evaluation and design of specialized local exhaust ventilation systems.
Nanomaterial Transport in the Lab: Nanomaterials removed from furnaces, reactors, or other enclosures should be put in sealed containers for transport to other locations. If nanomaterial product from a reactor is bound or adhered to a substrate, the substrate may be removed and put in a transport container. If the nanomaterials product is unbound and easily dispersible (such as in CNT synthesis using aerosolized catalyst), the removal from a reactor should be done with supplementary exhaust ventilation or a glove bag connected to a HEPA vacuum [8].

7.6 Work Practice Controls (Administrative Control)

- Standard Operating Procedures (SOPs) should be in place for working with specific nanomaterials (see appendix-1). Check list for SOP [8].
- Clean-up using HEPA vacuum and wet methods.
- Designated food/drink areas away from nanomaterials handling.
- Restrict areas to authorized personnel only.

7.7 Personal Protective Equipment (PPE)

Essential for minimizing exposures when handling nanomaterials. Basic PPE should always include: Gloves, eye protection, respirator, lab coat

Respirators: Respirators may be required for certain work operations (Surgical type masks are not respirators!).

- Filtration efficiency P100 recommended (NIOSH-approved)
- Studies show they are good down to 2.5nm
- Fit testing is required ensures no face seal leakage
- Critical because of nanoparticle size

Eye protection: Wear eye protection appropriate to the experimental conditions (for example, safety glasses, goggles, or face shields).

Safety glasses or face shields alone cannot protect against aerosols released with pressure, so goggles may be necessary for some nanomaterial processes.

7.8 Prevent Dermal Exposure to Nanomaterials (PPE-Gloves)

The ability of nanoparticles to penetrate the skin is uncertain at this point, so gloves should be worn when handling particulate and suspensions containing particulate.

- If working with dry particulate, a sturdy glove with good integrity should be used. If the nanoparticulate is in suspension, a glove having good resistance to the solvent should be used. Nanoparticles suspended in liquid may be more easily absorbed through the skin and represent more of an exposure hazard, so choose gloves appropriate to the solvent.
- Disposable nitrile gloves commonly used in many labs would provide good protection from nanoparticles for most procedures that do not involve extensive skin contact.
- Double gloving (for extensive skin contact).
- Gloves with gauntlets or extended sleeve nitrile gloves are useful in preventing contamination of lab coats or clothing.
- Change gloves routinely when using nanomaterials or if contamination is suspected.
- Keep contaminated gloves in plastic bags or sealed containers in your waste Satellite Accumulation Area until disposal.
- Wash hands and forearms thoroughly after handling nanomaterials.
- If contamination of clothing is a concern, use disposable lab coats and dispose of through hazardous waste pickup [8].

7.9 Transportation and Labeling Requirements

- The inner package must be labeled as nanomaterial.
- Inner containers must be a tightly sealed, rigid, and leak proof. Use tape on the cap to prevent the container from being unintentionally opened.
- Place the inner container in 6 mil(~152micron) plastic bag.
- The outer package must be filled with absorbent material to protect the inner container and absorb liquids during an inner container failure.
- In areas where easily dispersible nanoparticles are in use, post signs indicating the hazards, control procedures, and personal protection equipment that is required.

- If necessary, use the Chemical Hygiene Plan “Designated Area” sign available from the EHS Office to label the fume hood, lab bench, or lab itself.

7.10 Fire and Explosion Hazards

- Consider the higher reactivity of many nanoscale materials as suggesting that they be treated as potential sources of ignition, accelerants, and fuel that could result in fire or explosion [9].
- Nanoparticulate can be anticipated to have a greater potential for explosivity than micron sized particles, because of their increased reactivity.
- They may also have greater catalytic potential. Fire and explosions may be expected to be of greatest concern when reactions are scaled up to pilot plant levels.
- Both carbonaceous and metal dusts can burn and explode if an oxidant such as air or an ignition source is present [8].
- Determination of lower flammability limits using standard test bomb protocols may be necessary before scale-up. Contact the EHS Office for information on flammability testing protocols.

7.11 Prevent Contamination of Laboratory Surfaces

- Fume hood or enclosure surfaces should be wet-wiped after each use or at the end of the day.
- Alternatively use of bench liners would also prevent contamination. Bench liners, if contaminated, must be disposed of as hazardous waste. Do not dry sweep or use compressed air for cleanup.

7.12 Spill Cleanup

- Depending upon the quantity of nanomaterials in use in the lab, each lab should consider having the following items in a nanoparticle spill kit: barricade tape, nitrile gloves, disposable P100 respirators, adsorbent material, wipes, sealable plastic bags, walk-off mat (e.g. Tacki-MatTM).
- Minor spills or small quantities of nanomaterial can be wiped up using wet wiping for solid material and absorbent wipes for suspensions.
- Larger spills can be cleaned using a vacuum cleaner specially fitted with a HEPA filter on the exhaust to prevent dispersion into lab air. A reliable model of HEPA vacuum is the Nilfisk GM80CR. A log of HEPA vacuum use should be maintained so that incompatible materials are not collected on the HEPA filter. HEPA filter change-out should be done in a fume hood.

7.13 Waste Handling

- Currently there are no specific EPA regulations or guidelines for the proper disposal of nanomaterials.
- WSU will handle all nanomaterial waste as hazardous waste.
- DO NOT put material from nanomaterial – bearing waste streams into the regular trash or down the drain.
- Contaminated paper, PPE, wipes, tips should be collected in leak tight poly bags and submitted as hazardous solid waste.
- Pure nanomaterials in solid or powder form should be containerized and submitted as hazardous waste.
- Nanomaterials dissolved in solvents or formulations should be collected and submitted as a hazardous waste mixture.
- Submit all hazardous waste using the online form available on the EHS website.

7.14 Exposure Monitoring

Currently, it is unclear which metrics associated with exposures to engineered nanomaterials are most important from a health and safety perspective. The mass-based metric is traditionally used to characterize toxicological effects of exposure to air contaminants. Real-time measurement of aerosolized particles, including primary nanoparticles and agglomerates, play an important role in identifying nanomaterial emissions and evaluating control systems during field surveys. The measuring devices used to evaluate controls in the workplace should be portable and robust. Information about readily available instruments and techniques for nanoparticle monitoring (Table 4) has been summarized and discussed in technical reports.

Table 4: Summary of instruments and techniques for monitoring nanoparticle emissions in nanomanufacturing workplaces

Metric	Instrument	Remarks
Aerosol concentration	CPC	Real-time measurement. Typical concentration range of up to 400,000 particles/cm^3 for stand-alone models with coincidence correction; 100,000 particles/cm^3 for hand-held models.
	DMPS	SMPS often uses a radioactive source. FMPS uses electrometer-based sensors. Concentration range from 100−107 particles/cm^3 at 5.6 nm and 1−105 particles/cm^3 at 560 nm.
Surface area	Diffusion charger	Need appropriate inlet pre-separator for nanoparticle measurement. Total active surface area concentration up to 1,000 $\mu m^2/cm^3$.
	ELPI	Real-time size-selective detection of active surface area concentration. 2×104–6.9×107 particles/cm^3 depending on size range/stage.
Mass	Size selective static sampler	Low pressure cascade impactors. Micro-orifice impactors.
	TEOM	EPA standard reference equivalent method.
Aerosol concentration by calculation	ELPI	
Surface area by calculation	DMPS	
DMPS and ELPI used in parallel		Surface area is estimated by difference in measured aerodynamic and mobility diameters.
Mass by calculation	ELPI	Calculated by assumed or known particle charge and density.
	DMPS	Calculated by assumed or known particle charge and density.

CPC=condensation particle counter; DMPS=differential mobility particle sizer; SMPS=scanning mobility particle sizer; FMPS=fast mobility particle sizer; ELPI= electric low pressure impactor; TEOM=tapered element oscillating microbalance [11]

8. Summary

- The safety of researchers and workers advancing the field of nanotechnology is as important as the field itself.
- Assume all nanoparticles are hazardous.
- Minimize your risk by handling nanoparticles in solution to prevent the generation of dust/aerosols that could lead to inhalation.
- Understand the risks and implement measures to keep yourself safe!

- EHS at WSU is here to help you and your students against the potential hazards of nanotechnology and nanoproducts.

Definitions

Aerosol – a material that, while not gaseous itself, remains suspended in air for prolonged periods. Typical examples include dust, and fine-droplet liquid paint or hairspray.
Aggregate/aggregation – a material that is composed of a large number of small components which have come together as clusters, usually with branching, porous shapes. Aggregation is the process whereby the many small components form clusters, and can be driven by gravity or other forces.
Alzheimer's disease - a progressive, irreversible, neurodegenerative disease characterized by loss of function and death of nerve cells in several regions of the brain, leading to loss of attention, memory, and language. Its cause is unknown.
Antibody - a protein produced by the immune system as a response to a foreign substance, or antigen.
Antigen – a foreign substance that triggers the production of antibodies by the immune system.
Apoptosis – or "programmed cell death" is the process of cellular suicide that can be initiated for several reasons: when extensive cellular damage occurs, when the cell is no longer needed within the organism, and in embryonic development, among others. Apoptosis is different from cell necrosis (a form of traumatic cell death due to physical or biological injuries) in its biochemical and morphological aspects. Aberrations in apoptosis contribute to various diseases, such as cancer.
Atomic Force Microscopy - a scanning-probe form of surface microscopy that can image and manipulate matter at the nanometer scale.
Autoimmune diseases – a group of disorders where overactive functioning of the immune system results in the immune system producing antibodies or autoreactive T cells (a type of white blood cells) against its own tissue.
Cancer – disease characterized by rapid and uncontrolled cell division.
Chelator – a chemical agent that binds reversibly to a metal ion, forming a metallic complex.
Chronic disease – disease lasting a long time, which is ongoing or recurring, not caused by an infection and not contagious.
Clearance – the removal of particles or substances out of an organism, usually via urine or stool.
Crohn's disease – a chronic inflammatory disease of unknown cause that may affect any part of the gastrointestinal tract, most commonly the small bowel, as well as other organs. Symptoms of the disease include diarrhea, abdominal pain, and excessive weight loss.
Cytokine - a small protein released by cells that has a specific effect on interactions between cells, on communications between cells, or on the behavior of cells.
Cytoplasm - includes both the fluid (cytosol) and the organelles contained within a cell.
Degenerative disease - disease characterized by progressive deterioration of function or structure of tissue.
DNA is a nucleic acid found within the nucleus of each cell, carrying genetic information on cell growth, division, and function. DNA consists of two long strands of nucleotides twisted into a double helix and held together by hydrogen bonds. The sequence of nucleotides determines hereditary characteristics. Each cell contains an identical, complete copy of the organism's DNA, with differing cell characteristics determined by differences in gene expression.

Endemic disease – disease constantly present in and limited to people living in a certain location.
Endogenous – substances originating within, or synthesized by an organism (e.g. hormones and neurotransmitters).
Endoplasmic reticulum - a membrane network that extends throughout the cytoplasm and is involved in the synthesis, processing, secretion, and transport of proteins throughout the cell.
Endothelium - the layer of cells that line the interior surface of all parts of the circulatory system, including the heart, and blood vessels. Specialized endothelial cells perform important filtering functions in the kidney and at the blood-brain barrier.
Enzyme – a protein that acts as a catalyst in a biochemical reaction.
Epidemiology - the branch of medical sciences that studies various factors influencing the incidence, distribution, and possible control of diseases in human population.
Etiology – set of causes or origin of a disease.
Exogenous - substances originating outside an organism.
Fibroblast – a connective-tissue cell that secretes collagen and other components of the extracellular matrix. It migrates and proliferates during wound healing and in tissue culture.
Gene – a sequence of nucleotides (DNA) that defines a protein. Genes are the fundamental unit of heritability, and their collection in an individual organism (its genome) represents a code or protocol for the growth and development of that individual. Genes are arranged along the length of chromosomes, of which each species has a fixed number.
Genotype – the genetic constitution of an organism.
Granuloma – tissue resulting from aggregation of inflammation-fighting cells unable to destroy foreign substances.
Hydrophilic - having an affinity for water, or causing water to adhere.
Hydrophobic - having no affinity for water, or repelling water.
Inflammation - a localized protective response, produced by tissue injury that servs to destroy or arrest both the agent and the affected tissue. Blood vessel permeability locally increases, and the area becomes heavily populated with white blood cells. Signs of inflammation are redness, swelling, pain, and sometimes loss of function.
Ischemia - decrease in the blood supply to an organ, tissue, limb, or other part of a body caused by the narrowing or blockage of the blood vessels. Ischemia may lead to a shortage of oxygen (hypoxia) within the tissue and may result in tissue damage or tissue death.
Lavage - washing out or clearance of a body cavity, organ, or system.
Lung burden - the product of exposure rate and residency time of particulate matter inhaled into the lungs.
Lymph – a fluid containing white blood cells, proteins, and fats; can also carry bacteria, viruses, and cancer cells around the body. Lymph is collected from the tissues and returned to the circulatory system.
Lymphatic system – the network of vessels, nodes, and organs (spleen, thymus) that produce, store, and carry lymph. The lymphatic system lacks a central pump, such as the heart in the circulatory system, and must rely on muscles pumping.
Lymphoedema - a condition in which lymph nodes become enlarged and prevent lymph fluid from passing through them.
Macrophage - a phagocytic tissue cell of the reticuloendothelial system that is derived from the blood monocyte. The monocyte migrates from the blood into tissues where it transforms into a

macrophage. Macrophages are present in most tissues. Macrophages ingest and process degenerated cells and foreign invaders, such as viruses, bacteria, and particles. The long-lived macrophages are reservoirs of HIV.
Mesothelioma – a rare form of cancer occurring in the lining of the lungs and chest cavity.

Mitochondrion - an organelle responsible for most of the oxidative metabolism in the cell. Mitochondria generate energy (in the form of ATP, adenosine triphosphate) by breaking down glucose (a type of sugar).
Monocyte - the largest form of a white blood cell, with a kidney-shaped nucleus; its function is the ingestion of foreign invaders, such as bacteria, tissue debris, and particles. Monocytes belong to the group of phagocytes, and mature into various macrophages in tissue.
Murine – pertaining to the rodent family, i.e. rats and mice.
Nanoparticulate matter – a collection of particles with at least one dimension smaller than 1 micron yet larger than atoms and molecules.
Neutrophil - an immune cell that ingests and degrades foreign organisms. Neutrophils are the most abundant type of white blood cells, and are the first to reach the site of an infection to attack foreign antigens.
Oxidative stress - an imbalance in favour of pro-oxidant versus antioxidant chemicals, potentially leading to damage to biomolecules.
Parkinson's disease - a progressive disorder of the nervous system manifested by muscle tremors and rigidity, decreased mobility and slow voluntary movements.
Particulate matter – airborne particles of solids and/or liquids with sizes ranging from several nanometers to several hundred microns.
Phagocyte - cell that ingests and kills foreign intruders via the process called phagocytosis. Three examples are: monocytes, macrophages, and neutrophils.
PM0.1 – particulate matter having a diameter smaller than 0.1 microns (100 nm).
PM10 – particulate matter having a diameter smaller than 10 microns.
PM2.5 – particulate matter having a diameter smaller than 2.5 microns.
Pneumoconiosis – lung disease due to permanent deposition of substantial amounts of particules in the lungs and by the tissue reaction to its presence. Its severity varies from relatively harmless forms of sclerosis to destructive fibrosis and scarring of the lungs.
Protein – molecule containing a long chain of amino acids in the order specified by a gene's DNA sequence. Proteins can be, for example, enzymes, hormones, and antibodies.
Quantum dot - semiconductor crystals with a diameter of a few nanometers, having many properties resembling those of atoms.
Receptor - A protein or large molecule on the surface of a cell that binds selectively to specific substances (ligands).
Reperfusion - restoration of blood flow.
Reticuloendothelial system - a part of the immune system that consists of phagocytic cells, including macrophages and macrophage precursors, specialized endothelial cells lining the sinusoids of the liver, spleen, and bone marrow, and reticular cells of lymphatic tissue (macrophages) and bone marrow (fibroblasts).
Rheumatoid arthritis - chronic, autoimmune, inflammatory disorder affecting the connective tissue lining the joints. Symptoms include pain, swelling, stiffness, and deformities. It can extend to organs.
Scleroderma – a degenerative, autoimmune disease of the connective tissue, characterized by

the formation of fibrous tissue (collagen) which surround the joints, blood vessels and sometimes internal organs.
Systemic lupus erythematosus - a chronic, autoimmune disorder. Symptoms include fatigue, butterfly-shaped facial rash, inflammation of the joints, tendons, connective tissues, and organs: heart, lungs, blood vessels, brain, kidneys, and skin.

Toxicology - the branch of medical and biological science studying the nature, adverse effects, detection, and treatment of poisons on living organisms. A fundamental principle of toxicology is that any substance is poisonous if given in a large amount. From the study of cancer-causing substances, carcinogens, it appears that there are some materials for which there is no safe dose, no level of exposure below which they do not cause cancer.
Transcription factor - a protein that binds to enhancer elements in DNA to regulate the level of transcription and expression of certain genes.
Translocation – the process of transit of particles or substances within an organism.
Ulcerative colitis – a chronic disease of unknown cause characterized by inflammation of the colon producing ulcerations. Symptoms are: abdominal pain, cramps, loose discharges of pus, blood, and mucus from the bowel, and weight loss.
Ultrafine particles (UFP) - nanoparticles with size smaller than 100 nm

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Appendix

Appendix-1: Check list for Nanomaterials Standard Operating Procedure

Nanomaterials: Describe material and process below and then check practices that should be used.

Name: Lab Room Number(s): PI:	Nanomaterials		
Safe Handling Practices	1.	2.	3.
SDSs, Toxicity Info -Do you have SDSs for your nanomaterials? -Do SDSs report results of tests on nanomaterials or do they refer to bulk material? -Have you researched toxicity of your material?			
Prevention of Inhalation Exp. -Use in fume hood -Use in biosafety cabinet -Use in other exhausted enclos. -Synthesis in furnace/reactor -Is reactor in fume hood -Are furnace gasses exhausted -Are potential emission points exhausted -Use on lab bench (reference for low toxicity) -Transport within lab in sealed container			
Skin Protection -Gloves worn and type used -If solvent suspension, glove resistant to solvent -If skin contamination likely, double gloves -Gloves with gauntlets or extended sleeves -Frequency of changing gloves -Lab coats (cloth or disposable)			
Eye Protection -Type of eye protection (safety glasses, goggles, face shield) -Goggles worn for processes with high energy			

Handling Practices, Cont.	Nanomaterials		
	1.	2.	3.
Prevent Lab Contamination -Wet wipe surfaces and how often -Use bench liners -Access to HEPA vacuum			
Signage and Labeling -Signs for nanomaterial use -Labels on container indicate nanoscale material			
Spills -Is there potential for spills -Spill kit available? -Wet wiping for minor spill cleanup -Access to HEPA vacuum -Respirators for spills -Type of respirator (P100) -Obtained from EHS Office and fit tested			
Waste Nanomaterial -Do you have waste nano mat? -Do you collect waste in SAA? -Do you collect contam. Materials as waste? -Label waste as nanoscale			
Transportation Off-Site -Do you need to ship nanomaterials off-site? -Have you contacted EHS office for DOT regulations?			