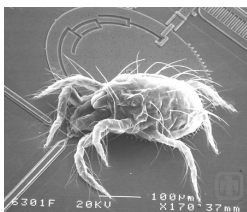


The Scale of Things – Nanometers and More

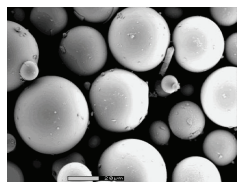
Things Natural



Dust mite
200 μm



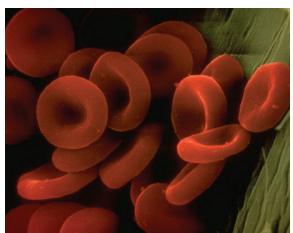
Ant
~ 5 mm



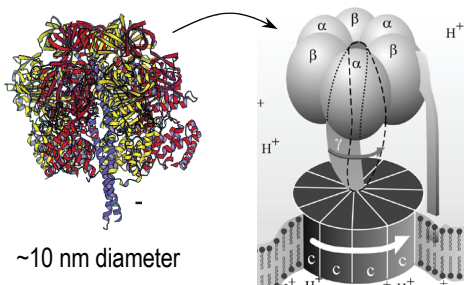
Fly ash
~ 10-20 μm



Human hair
~ 60-120 μm wide

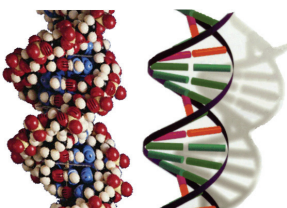


Red blood cells
(~7-8 μm)

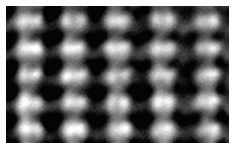


~10 nm diameter

ATP synthase

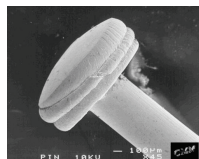


DNA
~2-1/2 nm diameter

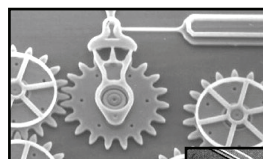


Atoms of silicon
spacing 0.078 nm

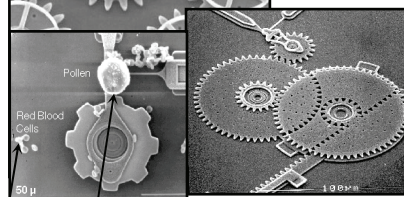
Things Manmade



Head of a pin
1-2 mm



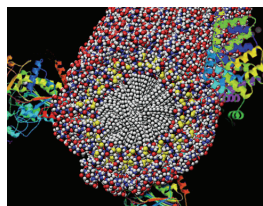
MicroElectroMechanical (MEMS) devices
10 -100 μm wide



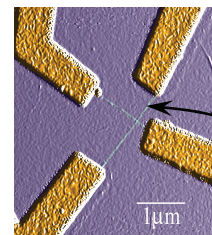
Pollen grain
Red blood cells



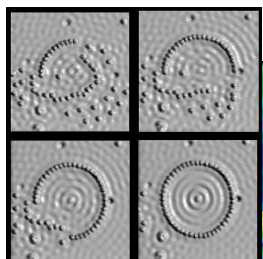
Zone plate x-ray "lens"
Outer ring spacing ~35 nm



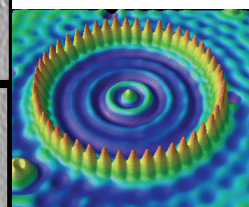
Self-assembled, Nature-inspired structure
Many 10s of nm



Nanotube electrode

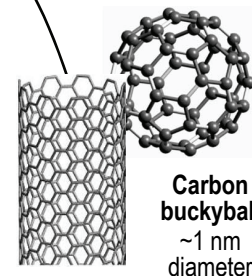


Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm

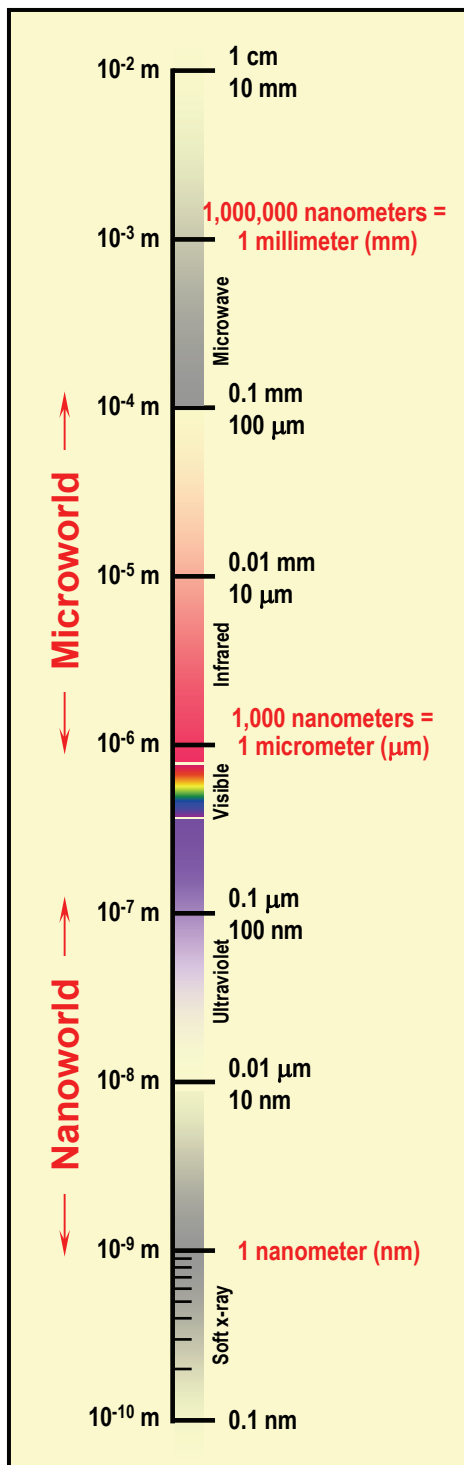


The Challenge

Fabricate and combine nanoscale building blocks to make useful devices, e.g., a photosynthetic reaction center with integral semiconductor storage.



Carbon buckyball
~1 nm diameter
Carbon nanotube
~1.3 nm diameter





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Nanomaterial Laboratory Safety

ES&H Course 161

Rev. 12/16/2010

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Course Purpose and Objectives

Nanomaterials and their unique size-dependant properties are of considerable scientific interest -

- Course purpose
 - Provide information on the special hazards that may be associated with the handling of free or unbound engineered nanoparticles (UNP)
 - Describe how to minimize these hazards
- Upon completion of the course you will be able to:
 - Define engineered nanoparticles and UNPs
 - Identify health, safety, and environmental hazards posed by UNPs
 - Explain how to control personal and environmental exposure to UNPs
 - Understand transportation and waste management requirements for UNPs

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Nanoscale materials are of considerable scientific interest because some material properties can change at this scale. These changes challenge our understanding of hazards, and our ability to anticipate, recognize, evaluate, and control potential health, safety, and environmental risks.

This course will provide information on the special hazards that may be associated with the handling of free or unbound engineered nanoparticles (UNP), and describe SLAC policies and controls for managing environmental, safety, and health concerns associated with laboratory activities involving nanomaterials.

SLAC staff who work with nanomaterial in laboratories (nanoparticle workers and their supervisors) must complete this course upon initial assignment. Visiting scientists, guest researchers, and other lab users who are not SLAC employees or subcontractors must take ES&H Course 161 or demonstrate that they understand applicable chemical hygiene principles. This can be accomplished by providing acceptable proof of nanomaterial laboratory safety training from another institution or passing an exam.

What are nanomaterials?

Engineered nanoparticles

- intentionally created (in contrast with natural or incidentally formed) particle with dimensions less than 100 nanometers.
 - Definition excludes:
 - biomolecules (proteins, nucleic acids, carbohydrates)
 - materials for which an occupational exposure limit, national consensus standard, or regulatory limit exists for the nanoscale particles
 - UNP incapable of becoming airborne or not expected to be generated or released
 - Nanoscale forms of radiological materials
 - Nanoparticles incidentally produced by human activities or natural processes, such as diesel engines and forest fires

The scope of SLAC's Nanomaterial safety plan is concerned with:

Engineered nanoparticles, that is, intentionally created – in contrast with natural or incidentally formed – engineered nanomaterials with dimensions of less than 100 nanometers. This definition excludes biomolecules (proteins, nucleic acids, and carbohydrates) and materials for which an occupational exposure limit (OEL), national consensus, or regulatory standard exists. Nanoscale forms of radiological materials are also excluded from this definition.

What are nanomaterials?

DOE Definition =

Unbound Engineered Nanoparticle (UNP)

- Engineered nanoparticles not contained within a matrix
=> could become separately mobile and a potential source of exposure.
- An engineered nanoparticle fixed within a polymer matrix is incapable of becoming airborne, would be “bound,” while
 - such a particle suspended as an aerosol or in a liquid would be “unbound”

Unbound engineered nanoparticles (UNP) are defined by the DOE to mean those engineered nanoparticles that, under reasonably foreseeable conditions encountered in the work, are not contained within a matrix that would be expected to prevent the nanoparticles from being separately mobile and a potential source of exposure. An engineered nanoparticle dispersed and fixed within a polymer matrix, incapable, as a practical matter, of becoming airborne, would be “bound”, while such a particle suspended as an aerosol or in a liquid would be “unbound”.

Nanomaterials Are Not New

- We have been exposed to natural and man-made nanoscale particles for years:
 - Diesel exhaust
 - Welding fumes
 - Carbon Black
 - Volcanic ash (which can travel thousands of miles in clouds)
 - Cigarette smoke and other combustion products
 - Viruses fall within the nanoscale (10nm to 300nm in size)
- Many have chronic effects that may take years to develop.
- Many occupational exposure limits account for nano scale

Humans have always been exposed to nanoscale particles via dust storms, volcanic eruptions, and other natural processes. Human activity and technological advancement has increased the variety of nanoparticles to which we are exposed. While the body is well adapted to protect itself from exposure to tiny particles, and the vast majority cause little ill effect, some can cause appreciable harm and many have chronic effects that may take years to develop.

Potential for Novel Toxicity and Reactivity

- The properties of nanoscale materials may be significantly different from bulk materials of the same composition
- => MSDS may be misleading or of limited value
- Among the new properties of nanoscale materials may be:
 - *Enhanced* toxicity of toxic materials
 - *New* toxicological properties not seen in bulk material
 - Some nanoparticles may be *pyrophoric* or readily combustible

While toxicity data is limited, we do know a great deal about how engineered nanoparticles behave

The properties of nanoparticles are often strikingly different from the properties of the same material in bulk, which forms the motivation for our scientific interest.

It should be noted that MSDSs may be misleading and should be considered of limited value when based on the bulk properties of the material, which has often proven to be the case.

Among the new properties of nanoscale materials may be:

- *Enhanced* toxicity of toxic materials
- *New* toxicological properties not seen in bulk material
- Some nanoparticles may be *pyrophoric* or readily combustible

Nanotoxicology is an emerging field, and early work was plagued by methodological problems. Our understanding is beginning to coalesce however, and we do know a great deal about how engineered nanoparticles behave. We will review some aspects to motivate our concern regarding the potential occupational hazards of nanoparticles.



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Potential Hazards

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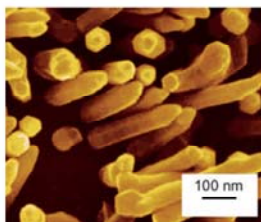
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Potential Hazards

Concern is *centered* on “*Unbound Nanoparticles*” which are:

- Not firmly attached to a surface
- Not part of a bigger item (e.g., microchip, cell membrane)
- Can result in exposure via inhalation, skin absorption or ingestion (or other nanospecific routes of exposure)



Zinc oxide nanorods affixed to a surface



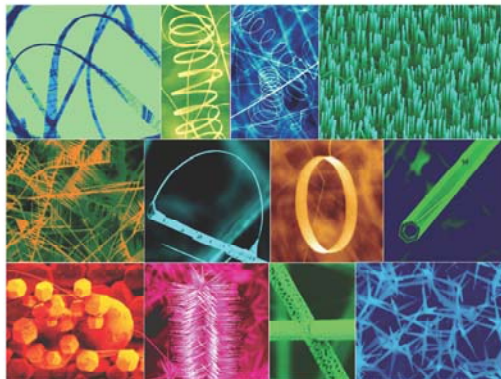
Harvesting carbon nanotubes

We are most concerned with unbound nanoparticles because they are capable of being dispersed. Routes of occupational exposure to free nanoparticles can occur by inhalation, skin absorption or ingestion, and we are most concerned about inhalation where their small size allows nanoparticles to deposit in the head airways and reach deep into the lungs.

Potential Hazards

- Toxic potential of novel nanoparticles is uncertain

- Many variables may effect toxicity:
 - size
 - shape
 - chemistry
 - crystal structure
 - water solubility
 - surface area
 - surface coating,
 - agglomeration state density
 - dispersability
 - porosity
 - surface charge
 - conductivity
 - contaminants
 - manufacturing method



A collection of nanostructures of ZnO
– they may have different toxicity profiles based on morphology.

The toxic potential of novel nanoparticles is not easily characterized and it is difficult to generalize. A wide range of chemistries are used in nanoparticle production, especially for research purposes, and the potential structures are almost unlimited. The photomicrographs above show various morphologies of zinc oxide, each one of which may have a different potential toxicity.

Potential Hazards

Drivers of toxicity include:

- Intrinsic elemental (chemical) toxicity
 - Lead, cadmium, etc.
 - Semiconductor nanocrystals (quantum dots, are intrinsically cytotoxic [toxic to cells])

=> Usual dose metric = mass
- Morphology driven toxicity
 - Fiber toxicity
 - Asbestos, fibrous zeolites, MMMF

=> Usual dose metric = fiber count
- Surface reactivity driven toxicity
 - Surface catalysis damaging reactions

=> Likely dose metric = surface area

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Drivers of nanoparticle toxicity include:

- 1. Intrinsic elemental (chemical) toxicity** – For usually soluble materials, individual atoms or ions may interfere with biological systems. Metals such as lead and cadmium are known to be toxic upon inhalation, ingestion or dermal exposure. Many uncoated quantum dots are intrinsically cytotoxic due to their metal content (e.g., lead, cadmium, selenium, etc.), and it has been suggested that their toxicity exceeds the sum of their components toxicity. Toxicological effects normally correlate to the mass of the material absorbed by the individual.
- 2. Morphology driven toxicity** – Fiber toxicity is an example; asbestos is a good example of a toxic nanomaterial, causing lung cancer and other diseases. Asbestos exists in several forms, with slight variations in shape and chemistry yet significantly varying toxicity. Fibrous zeolites and man-made mineral fibers are additional examples. Toxicological effects normally correlate to the number of fibers absorbed by the individual.
- 3. Surface reactivity driven toxicity** – Surface area is the key factor in catalysis and the generation of reactive oxygen species is enhanced by particles of very high surface area. See next slide.

Potential Hazards

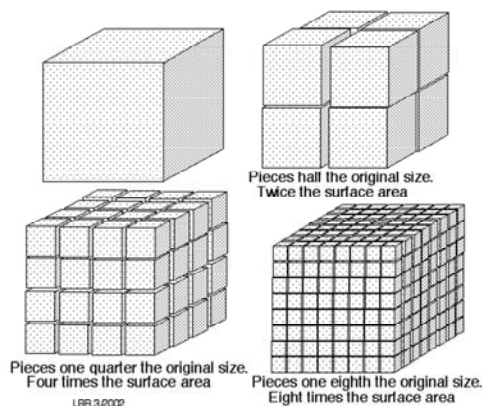
- Large particles that are minimally toxic - may become more toxic at the nanoscale:

- Apparent pulmonary toxicity of nano TiO₂, polystyrene, & carbon black
- not seen with microscale particles

Note: for TiO₂, true on equal mass basis but not on surface area basis

- This may be related to formation of reactive oxygen species with resulting damage to biomolecules

- High toxicity materials may become more toxic in the nanoscale, e.g., nickel, cobalt



For a given mass of particles, as the diameter of the particles decreases the number of particles increases exponentially and the specific surface area increases linearly. As particle size decreases below 10 nm, the number of molecules on the surface of the particle increases rapidly, at 4 or 5 nm roughly half of the molecules are on the surface. For a single walled carbon nanotube, every atom is on the surface.

There is significant evidence that many nanoparticles are uncharacteristically toxic when compared to their bulk properties due to the accelerated generation of reactive oxygen species that lead to biomolecule damage, inflammation, and even cell death.

Potential Hazards

Particle Size Dependent Toxicity Is Not New

- Crystalline silica – respirable fraction most toxic when for two reasons:
 - Deposited in alveolar portion of lungs, which lack effective clearance mechanisms
 - Increased surface area causes inflammation, scarring (oxidative stress/catalysis)



Silicosis Patient

X-ray of a patient suffering from fibrosis due to crystalline silica exposure

Silicosis is a dramatic example of particle size dependant toxicity. Micron sized crystalline silica particles are deposited in the upper respiratory tract with little effect. However smaller particles reach the alveolar spaces in the lungs where a cascade of effects leads to inflammation and lung scarring.

Potential Hazards

Ultrafine (Nano) Particulate Air Pollution is Associated With Disease

- Nanoparticles in air pollution are associated with cardiovascular disease and are seen to be a major influence on mortality rates
- Increases in admissions to hospitals for cardiovascular and respiratory problems are associated with increases in ultrafine particulate pollution

This may be relevant for engineered nanoparticles

Nanoparticles in air pollution - cardiovascular disease and mortality rates:

- Atmospheric particle pollution from automobile exhaust seems to have a major influence on mortality, with a strong association between increased cardiopulmonary mortality and living near major roads.
- Measurements of nanoparticle concentration near highways shows an exponential decrease over several hundreds meters away from traffic.
- Childhood cancers were also found to be strongly determined by prenatal or early postnatal exposure to oil-based combustion gases, primarily engine exhaust .
- Professional drivers show elevated rates of heart attack.
- The correlation between ambient particles exposure and heart disease has been established for 15 years – e.g., hospital admission for cardiovascular illness were noted to increase on days with high concentrations of particles.

Potential Hazards

- Some nanoparticles bypass barriers to distribution and travel
 - into bloodstream / passing through respiratory or gastrointestinal membranes.
- Translocation - nose to brain along olfactory nerve
 - Animals exposed Mn via left nostril only / Mn concentration increase left olfactory bulb
 - Manganism in welders, mimics Parkinson's disease



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Nanoparticles have been shown to bypass normal body barriers to distribution in at least the following:

- Through intact skin – sometimes
- Static skin application - no penetration; flexed skin - some penetration (follicle penetration); nitrile gloves offer the best protection
- Through the gastrointestinal epithelium – yes
- Through respiratory tract – yes
- Along nerve axons from the nose to the brain - yes

Potential Hazards

Summary:

- Toxicity may be highly dependent on many variables
 - difficult to generalize
- At the nanoscale:
 - Non-toxic materials may become toxic
 - Toxic materials may become more toxic
- Dissolution of particles may lead to chemical toxicity
- Nanoparticle shape may cause toxicity
- Toxicity may not occur at point of exposure

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Potential hazards of nanoparticles are summarized above.

It should be noted that there are currently no consensus occupational exposure limits for nanomaterials, although some occupational exposure limits do are affected by the ultrafine scale of the particles. Examples of the latter are: crystalline silica, and carbon black.

NOTE:

NIOSH has draft recommended exposure limits (RELs) for :

- 1.5 mg/m³ fine TiO₂;
- 0.1 mg/m³ ultrafine TiO₂
- Reflects greater inflammation & tumor risk of ultrafine on mass basis

For reference, the current American Conference of Industrial Hygienists (ACGIH) exposure limit (TLV, Threshold Limit Value) is 10 mg/m³



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Safe Work Practices

Safe Work Practices

SLAC follows* a prudent approach to handling nanomaterials of unknown toxicity and reactivity:

- Assume all nanoparticles are acutely toxic in the short run and chronically toxic in the long run, and handle them accordingly
- Handle and store potentially pyrophoric nanoparticles (e.g. metals) as though they may ignite when exposed to air/oxidants

*In conformance with the general principle in the National Research Council's *Prudent Practices in the Laboratory: Handling and Disposal of Chemicals*

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As a prudent measure, the SLAC Nanomaterial Safety Plan adopts the following approach:

- All nanoparticles are assumed to be acutely toxic in the short run and chronically toxic in the long run, and are to be handled accordingly
- Potentially pyrophoric nanoparticles (e.g. metals) are to be handled as though they may ignite when exposed to air or oxidants

Controls:

- Engineered controls work about as expected for nanoparticles
- Mechanical filters (HEPA) work exactly as predicted by classical filtration theory down to about 3 nm and fail progressively below this size
- Protective clothing works just about as expected – less air permeable fabrics do a better job of keeping out nanoparticles
- Effectiveness of gloves is still under investigation. They work pretty well (nitrile among the best), they may fail under some circumstances (can consider wearing two pair).

Safe Work Practices

Nanomaterial Safety Plan*

• Component of *SLAC Environment, Safety, and Health Manual*,
Chapter 40, "Hazardous Materials"

- The plan applies wherever nanomaterials, including precursors, intermediates, and wastes are used at SLAC
- Takes a graded approach based on the risk level:
 - Low-risk Level – Bound or Fixed Nanostructures
 - » Solid materials with imbedded nanostructures
 - » Solid nanomaterials with nanostructures fixed to the material's surface
 - Medium-risk Level – Nanoparticles suspended in liquids
 - High-risk Level – Dry, dispersible nanoparticles, aerosols, nanoparticle agglomerates/aggregates, or nanomaterials determined to be high risk based on a exposure & safety assessment

*Meets the requirement for SLAC to comply with DOE Policy 456.1, which stipulates the use of best practices and national consensus standards; meets requirements of DOE Notice 456.1, 1/5/2009.

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The Nanomaterial Safety Plan is found in Chapter 40 – Hazardous Materials of the SLAC Environment, Safety, and Health Manual. It can be accessed on line at:

<http://www-group.slac.stanford.edu/esh/eshmanual/references/hazmatPlanNano.pdf>

The plan takes a graded approach to safety based on the risk posed:

- Low-risk Level – Bound or Fixed Nanostructures
 - Solid materials with imbedded nanostructures
 - Solid nanomaterials with nanostructures fixed to the material's surface
- Medium-risk Level – Nanoparticles suspended in liquids
- High-risk Level – Dry, dispersible nanoparticles, aerosols, nanoparticle agglomerates/aggregates, or nanomaterials determined to be high risk based on a exposure & safety assessment

Safe Work Practices

Assigned risk-level determines: required review / approval & controls:

Risk	Proposal Reviewed */ Approved by	Controls and Work Practices
Low-risk Level	Division Safety Coordinator	NSC Approved SOPs
Medium-risk Level	Division Safety Coordinator	NSC Approved SOPs
High-risk Level	NSC	Project specific work plan

NSC = SLAC Nanoscience Safety Committee

* Exposure and Safety Assessment - All nanomaterial work will be reviewed for ES&H concerns

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The nanomaterial risk-level determines the appropriate review, approval, and work controls required. The Safety Coordinator of the appropriate Division (e.g., SSRL, LCLS, etc.) must review every **low-** and **medium-risk** level for ES&H concerns – note that in practice, most such work falls into categories such that most can be approved to follow existing standard operating procedures.

All work with **high-risk** level nanomaterials must be reviewed and approved by the SLAC Nanoscience Safety Committee (NSC). In such cases, researchers must submit a draft work plan to the Division Safety Coordinator, who will present the information to the NSC and communicate any special controls or requirements to the researcher.

Note:

- No nanomaterials may be brought on-site or manufactured until approved by the Division Safety Coordinator.
- All work or research with nanomaterials may only be performed by personnel who are authorized by their division and who have been properly trained.

Safe Work Practices

Consistent with research needs, handle nanoparticles in the least dispersible form possible:

- Best: attached to substrate
- Good: In liquid suspension
- Use great care: Dry powders, aerosol

Use Engineering Controls to Minimize Exposure Potential:

- Conduct any work that could generate engineered nanoparticles using engineered controls (e.g. laboratory hoods, glove boxes, glove bags) to minimize potential exposures

The least dispersible form of nanoparticles possible should be used that is consistent with research goals.

Conduct **any work** that **could generate engineered nanoparticles** using engineered controls (e.g. **laboratory hoods, glove boxes**, glove bags) to minimize potential exposures.

Safe Work Practices

When nanoparticles suspended in liquids are brought to the beam line or transported internally they must be:

- Transported in sealed containers
- Manipulated over an absorbent paper to capture any spills
- Work surfaces must be wiped with dampened adsorbent paper towels at the completion of the experiment (aqueous soap solution).

When nanoparticles suspended in liquids are brought to the beam line or transported internally within SLAC (e.g., between labs or from a lab to the beam line at SSRL or LCLS) they must be:

- Transported in sealed containers
- Manipulated over an absorbent paper to capture any spills
- Work surfaces must be wiped with dampened adsorbent paper towels at the completion of the experiment (aqueous soap solution)

Safe Work Practices

Administrative controls: Housekeeping

- Maintain all working surfaces free of nanoparticles contamination
 - Wipe surfaces with wet disposable wipes
 - Dispose of contaminated cleaning materials as segregated nanomaterial waste
 - Vacuum with HEPA-equipped vacuum cleaner (unless potentially pyrophoric)
 - Never use dry sweeping or compressed air

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Good chemical hygiene housekeeping practices must be followed when working with nanoparticles:

- Wipe surfaces with wet disposable wipes
- Dispose of contaminated cleaning materials as **segregated nanomaterial waste**
- Vacuum with HEPA-equipped vacuum cleaner (unless potentially pyrophoric)
- Never use dry sweeping or compressed air

Safe Work Practices

Administrative controls: Labeling and Storage

- Label storage containers of nanoparticles to indicate both the chemical contents and the nanostructure form, e.g., “nanoparticulate zinc oxide”
- Store nanoparticles in sealed containers (unbreakable, if possible)
- Use secondary containment for all liquid suspensions
- Label work areas “Nanoscale Materials in Use” – see Lab manager for appropriate sign

Labeling and Storage

- Label storage containers of nanoparticles to indicate both the chemical contents and the nanostructure form, e.g., “nanoparticulate zinc oxide”
- Store nanoparticles in sealed containers (unbreakable, if possible)
- Use secondary containment for all liquid suspensions
- Label work areas “Nanoscale Materials in Use” – see Lab manager for appropriate sign

Safe Work Practices

Administrative controls: Work Area Signage



Work area signage must be used as shown above. Appropriate signs can be provided by Safety Coordinators, Laboratory Managers, or control Operator at SSRL or LCLS.

Safe Work Practices

Personal Protective Equipment

- Follow laboratory safe operating procedures maintained by the Laboratory Manager & Division Safety Coordinator (SOPs approved by NSC)
- Typical recommended personal protective equipment
 - Lab coats
 - Eye protection (glasses, goggles, shield)
 - Face protection
 - Chemically resistant gloves: e.g., nitrile
 - Closed toe shoes
- All PPE must be worn and maintained as required by SLAC policy in the Chemical Hygiene Program
 - Contaminated items must be cleaned or disposed of as segregated nanomaterial waste

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Personal Protective Equipment

- Follow laboratory safe operating procedures maintained by the Laboratory Manager and Division Safety Coordinator (SOPs approved by NSC)
- Typical recommended personal protective equipment follow good chemical hygiene practice
 - Lab coats
 - Eye protection (glasses, goggles, shield)
 - Face protection
 - Chemically resistant gloves: e.g., nitrile
 - Closed toe shoes
- All PPE must be worn and maintained as required by SLAC policy in the Chemical Hygiene Program
 - Contaminated PPE must be cleaned or disposed of as segregated nanomaterial waste

Safe Work Practices

Personal Protective Equipment: Respirators

- Respirators or filtering facemasks should not be required*
- If you think you need to use a face mask or respirator, contact the ES&H industrial Hygiene Group, to set up an exposure evaluation.

*Engineered controls should be equipped with performance monitors

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Note - Respirators or filtering facemasks **should not be required**

Engineered controls should be more than adequate for safety. However, if you think you need to use a face mask or respirator, **contact the ES&H industrial Hygiene Group**, to set up an exposure evaluation.

Safe Work Practices

Transportation of Nanomaterials from SLAC to and from off-site locations:

- If hazardous per 49 CFR
 - Must be packaged, marked, labeled and shipped by DOT trained personnel per 49 CFR
- If suspected to be hazardous – follow above
- If not hazardous per usual standards
 - Still package in DOT 1 container

Contact the Division Safety Coordinator (SSRL, LCLS) with any questions.

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Transportation of Nanomaterials from SLAC to and from off-site locations:

- If hazardous per federal regulations, package, mark, and ship per 49 CFR.
Note that the material must be packaged, marked, labeled and shipped by DOT trained personnel per 49 CFR. There are DOT trained staff at SSRL, LCLS, and SLAC Shipping and Receiving – please contact the Safety Coordinator in the appropriate Division (e.g., SSRL, LCLS, etc.)
- If suspected to be hazardous – follow above
- If not hazardous per usual standards, still package in DOT 1 container (sealed container inner, absorbent, exterior container)
- Contact the Division Safety Coordinator (SSRL, LCLS) with any questions.

Safe Work Practices

Nanomaterial Waste

- Both regulated (classified as hazardous per 40 CFR) and unregulated waste containing nanoparticles must be handled in the same manner:
 - Collected in a bag or can in the fume hood as designated
 - Labeled with waste label, as appropriate
 - Labeled to indicate nanoparticle waste
 - Request pick up by the Waste Management
- Never place nanomaterial-bearing wastes in the trash or flush down the drain!

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Nanomaterial Waste

- Both regulated (classified as hazardous per 40 CFR) and unregulated waste containing nanoparticles must be handled in the same manner:
 - Collected in a bag or can in the fume hood or work area as designated
 - Labeled with waste label, as appropriate
 - Labeled to indicate nanoparticle waste
 - Request pick up by the Waste Management
- Never place nanomaterial-bearing wastes in the trash or flush down the drain!
- Note: SLAC waste management will provide appropriate, labeled containers. Contact the Division Safety Coordinator (SSRL, LCLS) with any questions.

Safe Work Practices

Emergency and Spill Procedures

- Access Control - restrict entry to affected area with barricade tape or another reliable means

Liquids

- Employ normal HazMat response based on the spilled material's known hazards
- Position absorbent walk-off mat at exit of access-controlled area.
- Clean spill using wet-wiping / HEPA vacuuming dedicated
- Place barriers (e.g., plastic sheeting) to minimize air currents across affected the surface

Dry Materials – Response should be part of approved work plan

- Position sticky walk-off mat at exit of access-controlled area.
- Clean spill using wet-wiping methods.
- Use a tested and certified HEPA vacuum; do not use dry sweeping or compressed air
 - Consider the possible air reactivity of nanoparticles prior to using a vacuum cleaner. Wastes
- Treat all clean-up equipment as contaminated.
- Manage all materials used for clean up and all debris nanomaterial-bearing waste
- Refer personnel exposed to nanomaterials to the SLAC Medical Department.

The appropriate emergency and spill procedures for nanoparticles are outlined above.

You are expected to understand the hazards of the material you are working with and to have planned for any potential spill or emergency before initiating the work. For example, work with nanoparticles suspended in liquids should be performed over an absorbent paper and wipes should be readily at hand. Internal transportation (lab to bench, or lab to beam line, etc.) of nanoparticles suspended in liquids should be in sealed containers.

Safe Work Practices

Medical Health Surveillance

- Baseline medical evaluation*

Offered to SLAC staff identified as:

- nanoparticle workers
- nanoscale research support activities (e.g., maintenance, lab supervisors, etc.)

Via supervisors must assign Course 161ME in STA for these employees

- Post-incident medical evaluation

- SLAC staff involved in exposure "incident"

Non-resident personnel are exempt

- Facility users, guest

* General physical exam, general blood work, pulmonary function test, and tests/exams as determined by the SLAC Medical Department

Baseline medical evaluations will be *offered* for SLAC staff designated as nanoparticle workers engaged in nanoscale science research or nanoscale research support activities. The baseline medical evaluation will include a comprehensive physical exam, pulmonary function test, and routine blood work. Other tests or exams will be offered at the discretion of the Medical Department. Non-resident personnel (for example, facility users) will be exempted from medical surveillance.

References – Hazards, Safe Handling, Storage

- Department of Energy, Nanoscale Science Research Centers, *Approach to Nanomaterial ES&H* (NSRC, Revision 3a, May 2008), <http://orise.orau.gov/ihos/Nanotechnology/files/NSRCMay12.pdf>
- National Institute for Occupational Safety and Health, *Approaches to Safe Nanotechnology: Managing the Health and Safety Concerns Associated with Engineered Nanomaterials* (DHHS (NIOSH) Publication No. 2009–125, March 2009), <http://www.cdc.gov/niosh/docs/2009-125/pdfs/2009-125.pdf>

SLAC

Creating a Safe, Secure and Sustainable Environment for Science

ES&H

Useful references for additional information are provided above. The SLAC Nanomaterial Safety Plan can be accessed at:

<http://www-group.slac.stanford.edu/esh/eshmanual/references/hazmatPlanNano.pdf>

For your future reference, Table 1, “Requirements by Risk / Material Form” from the SLAC Nanomaterial Safety Plan is provided as an attachment. Table 1 summarizes required controls, review, and approval for nanomaterial work.



The New York Times
nytimes.com

January 14, 2007

BERKELEY LEGAL

Teeny-Weeny Rules for Itty-Bitty Atom Clusters

By [BARNABY J. FEDER](#)



SLAC
NATIONAL ACCELERATOR LABORATORY



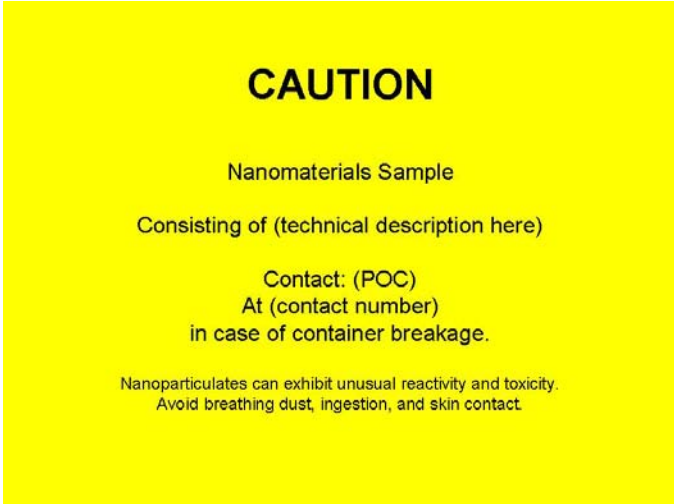
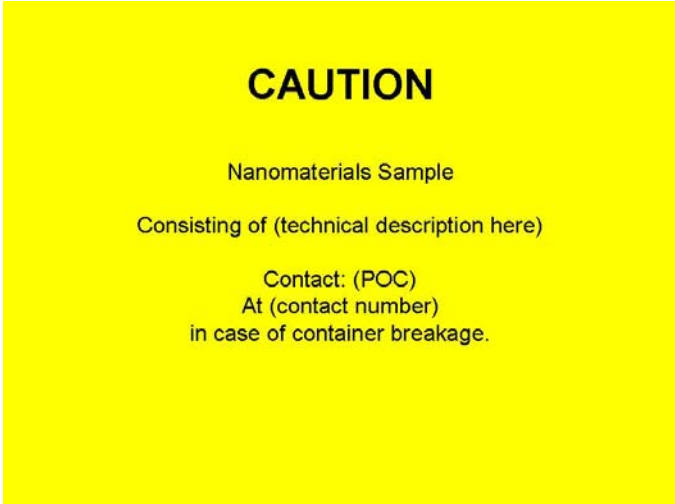
See attached reference

Table 1 Requirements by Risk / Material Form

From SLAC Nanomaterial safety Plan

Table 1 Requirements by Risk / Material Form

	Risk / Material Form		
	Low	Medium	High
Requirements	Bound or Fixed Nanostructures	Nanoparticles Suspended in Liquids	Dry Dispersible Nanoparticles and Agglomerates (or otherwise hazardous – see Section 3.1.3)
Review / Approval	SSRL Safety Coordinator	SSRL Safety Coordinator	NSC
PPE Requirements for Handling	Standard PPE required for the work area. No additional PPE is needed for this nanomaterial work.	Standard PPE required for the work area plus: <ul style="list-style-type: none"> ▪ Gauntlet-type nitrile gloves or wrist length disposable nitrile gloves with extended sleeves ▪ Eye protection: safety glasses with side shields for handling powders only. Chemical splash goggle for handling either powders or liquids. 	
Handling Requirements	<p>For work outside of a HEPA-filtered exhaust hood:</p> <ul style="list-style-type: none"> ▪ No mechanical abrasion ▪ No thermal stresses that might crack binder material ▪ Cover samples when practical to protect the sample, for example use a slide cover ▪ Store in sealed container when not in use 	<p>If there is a potential for particle aerosol formation, manipulate within a HEPA-filtered laboratory exhaust hood over adsorbent paper to capture any spills.</p> <p>Solutions brought to the beam line must be:</p> <ul style="list-style-type: none"> ▪ Transported in sealed containers ▪ Manipulated over an adsorbent paper to capture any spills <p>Work surfaces must be wiped with dampened adsorbent paper towels at the completion of the experiment (aqueous soap solution).</p>	<p>At a minimum:</p> <ul style="list-style-type: none"> ▪ Material must be manipulated within a HEPA-filtered laboratory exhaust hood over water-soaked adsorbent paper to capture any spilled materials. ▪ Exhaust hood work surfaces must be wiped with dampened adsorbent paper towels at the completion of the experiment (aqueous soap solution). ▪ When ejecting samples from a capillary, that sample must be directed to water for capture. Compressed nitrogen (<5 psi) or other inert gas must be used to eject the sample from the capillary tube. A covered beaker is best to contain any splash. This must be completed within a laboratory HEPA exhaust hood. ▪ Nanoscale materials brought to the beam line must be sealed within a sample holder, a capillary tube, or with at least two layers of Kapton, Mylar or cellophane tape. ▪ Only sealed containers are allowed at the beam lines for storage during an experiment. ▪ Experiments that involve gas flow over particles must include a water scrub of the gas exhaust to provide a final barrier to particle loss.
Spill Response	NA	Powder spills within an exhaust hood can be cleaned by using paper towels and an aqueous soap solution. Liquid spills within a hood can be cleaned with paper towels and then wiped with an aqueous soap solution. For spills outside of an exhaust hood, control access to the area and immediately notify the laboratory supervisor.	

	Risk / Material Form		
	Low	Medium	High
Requirements	Bound or Fixed Nanostructures	Nanoparticles Suspended in Liquids	Dry Dispersible Nanoparticles and Agglomerates (or otherwise hazardous – see Section 3.1.3)
Posting	No posting requirements	Post required sign at each designated nanomaterial workstation (beam line hutch and laboratory exhaust hood) for the duration of experiment. See Section 3.4.5, "Marking, Labeling, and Signage".	
Labeling of Containers	Follow the labeling requirements list below in Section 5, "Transportation of Nanomaterials".		
Transportation and Labeling	<p>Any nanomaterial that meets the definition of hazardous materials according to 49 CFR 171.8 (http://www.gpoaccess.gov/cfr/) or has known hazardous properties (toxic, flammable, reactive) must be shipped according to the SLAC Shipping Requirements for Hazardous Materials (SLAC Shipper Form, https://www-bis1.slac.stanford.edu/Public/shipper/shipintro.asp)</p> <p>Other nanomaterials may be carried in private vehicles when labeled and packaged as follows:</p> <p>Labeling:</p> <ol style="list-style-type: none"> The inner package must be labeled as follows: <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;">  <p>For dry particulates</p> </div> <div style="text-align: center;">  <p>For non-particulates</p> </div> </div> <p>Packaging:</p> <ol style="list-style-type: none"> 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 a >=6 mil plastic bag. The outer package (sealed cardboard box "or" sealed plastic container) must be filled with absorbent material to protect the inner container and absorb liquids during an inner container failure. 		
Waste Management	All waste in contact with nanomaterials must be disposed as hazardous waste (eg, swabs, Kim wipes, blotter paper, beakers, flasks, tape, sample holders). Chemicals containing nanomaterials must NOT be released to the sink or disposed in the regular trash.		

	Risk / Material Form		
Requirements	Low	Medium	High
	Bound or Fixed Nanostructures	Nanoparticles Suspended in Liquids	Dry Dispersible Nanoparticles and Agglomerates (or otherwise hazardous – see Section 3.1.3)
	<ol style="list-style-type: none"> 1. Waste containers: <ol style="list-style-type: none"> a. Liquids: must be stored in a rigid leak proof container. b. Particulates: must be stored in a rigid leak proof containers OR >=6 mil plastic bags. 2. Satellite accumulation areas: <ol style="list-style-type: none"> a. Liquids: must be stored in a secondary tray on the bench top or in a HEPA exhaust hood. b. Particulates: must be stored in a secondary container inside the designated nanomaterials HEPA-filtered exhaust hood. Waste must be placed into a clean secondary bag, within the HEPA exhaust hood, before transferring to the 90-day area. 3. Waste container labeling: <ol style="list-style-type: none"> a. No formulas, spell out the chemical name. b. The contents line on the label must contain the chemical composition and the word NANOMATERIALS. c. A second label is required on the outside of the bag stating CONTAINS NANOMATERIALS. 		