SLAC NATIONAL ACCELERATOR LABORATORY

ENVIRONMENT, SAFETY & HEALTH DIVISION

Nanomaterial Safety Plan

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Executive Summary

The Department of Energy (DOE) has made clear that it expects those engaged in the emerging field of nanotechnology to act responsibly in evaluating and controlling the associated environmental, health, and safety risks.

This plan is intended to demonstrate SLAC's compliance with Department of Energy Order 456.1A, "The Safe Handling of Unbound Engineered Nanoparticles" (DOE O 456.1A), which requires the review of best practices and national consensus standards to protect workers, the public, and the environment, and sets forth requirements for

- Providing procedures and controls that will protect workers and the environment while recognizing the uncertainty associated with nanomaterials – the hazards of which have not been determined – and reduce to an acceptable level the risk of worker injury, worker ill-health, and negative environmental impacts
- Promoting consistency in policy and procedures among DOE contractor laboratories

This document sets forth required practices at the SLAC National Accelerator Laboratory (SLAC) for managing environmental, safety, and health (ESH) concerns associated with

- *Engineered* nanomaterials, that is, intentionally created – in contrast with natural or incidentally formed – engineered nanomaterials with dimensions of less than 100 nanometers.
- *Nanoparticles*, that is, dispersible particles having two or three dimensions greater than 0.001 micrometer (1 nanometer) and smaller than about 0.1 micrometer (100 nanometers) and that may or may not exhibit a size-related intensive property.
- *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.
- Precursors, intermediates, and wastes used during, or resulting from, synthesizing such nanomaterials

Personnel should treat "all new compounds, or those of unknown toxicity, as though they could be acutely toxic in the short run and chronically toxic in the long run".

Nanomaterials will be managed in a manner consistent with the known risks and SLAC will follow a graded approach in specifying controls. The ESH coordinator will approve work for low- and medium-hazard materials. For high-hazard materials, approval will be granted either through a directorate-specific business process approved by the nanomaterial safety program manager or jointly by the nanomaterial safety program manager and ESH coordinator. (See Section 3.1, "Work Planning and Approval", for more details.)

The requirements of this document apply wherever the above materials are handled or used at SLAC. This includes *laboratory-scale* activities involving chemical containers, reaction vessels, material transfers, and other handling of substances that are designed to be easily and safely manipulated by one person.

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Acronyms

AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute
ASTM	ASTM International
CFR	*Code of Federal Regulations*
DOE	Department of Energy
ESH	environment, safety, and health
FAR	Federal Acquisition Regulations
GSA	General Services Administration
hazmat	hazardous material
HEPA	high-efficiency particulate air
ICAO	International Civil Aviation Organization
LTL	less-than-truckload
MCEP	Motor Carrier Evaluation Program
SDS	safety data sheet
NIOSH	National Institute for Occupational Safety and Health
NSRC	Nanoscale Science Research Center
OEL	occupational exposure limit
PPE	personal protective equipment
UNP	unbound engineered nanoparticle

1 Introduction

Nanoscale materials are of considerable scientific interest because some material properties can change at this scale.[1] These changes challenge our understanding of hazards, and our ability to anticipate, recognize, evaluate, and control potential environmental, health, and safety risks.

Exposures to these materials may occur through inhalation, dermal contact, and ingestion.[2] Animal studies indicate that low-solubility ultra-fine particles might be more toxic than larger ones on a mass-for-mass basis. Because of their tiny size, they can penetrate deep into the lungs and may translocate to other organs following pathways not demonstrated in studies with larger particles.

The nanoparticulate forms of some materials show unusually high reactivity, especially for fire and explosion, and in catalytic reactions. Engineered nanoparticles and nanostructured porous materials have been used effectively for many years as catalysts for increasing the rate of reactions or decreasing the temperature needed for reactions in liquids and gases. Depending on their composition and structure, some nanomaterials may initiate catalytic reactions that would not otherwise be anticipated from their chemical composition.

The Department of Energy (DOE) has made clear that it expects those engaged in the emerging field of nanotechnology to act responsibly in evaluating and controlling the associated environmental, health, and safety risks.

Although there is limited specific guidance on evaluation and control of exposures posed by nanomaterials, preliminary research suggests that some controls used in conventional laboratory settings work effectively to control exposure.

1.1 Purpose

This plan is intended to

- Provide procedures and controls that will protect workers and the environment while recognizing the uncertainty associated with nanomaterials – the hazards of which have not been determined – and reduce to an acceptable level the risk of worker injury, worker ill-health, and negative environmental impacts
- Promote consistency in policy and procedures among DOE contractor laboratories

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1 ASTM International (ASTM) E2456-2006 (reapproved 2012), "Standard Terminology Relating to Nanotechnology" (ASTM E2456-2006), uses the term *transitive nanoparticles* to refer to nanoparticles that exhibit a size-related intensive property that differs significantly from that seen in fine particles or bulk materials.

2 National Institute for Occupational Safety and Health, Approaches to Safe Nanotechnology: Managing the Health and Safety Concerns Associated with Engineered Nanomaterials (DHHS [NIOSH] Publication 2009-125), p. 12

1.2 Scope and Applicability

This document sets forth required practices at the SLAC National Accelerator Laboratory (SLAC) for managing environmental, safety, and health (ESH) concerns associated with the following:

- *Engineered* nanomaterials, 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.
- *Nanoparticles*, that is, dispersible particles having two or three dimensions greater than 0.001 micrometer (1 nanometer) and smaller than about 0.1 micrometer (100 nanometers) and that may or may not exhibit a size-related intensive property.[3]
- *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.[4] 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*.
- Precursors, intermediates, and wastes used during, or resulting from, synthesizing such nanomaterials

The requirements of this document apply wherever the above materials are handled or used at SLAC. This includes *laboratory-scale* activities involving chemical containers, reaction vessels, material transfers, and other handling of substances that are designed to be easily and safely manipulated by one person.

These requirements are in addition to those covering the management, storage, use, and transportation of chemicals and hazardous materials contained in Chapter 40, “Chemical Lifecycle Management”, Chapter 52, “Hazardous Materials and Waste Transportation”, Chapter 53, “Chemical Safety”, and Chapter 17, “Hazardous Waste”.

1.3 Standards

This program, which follows the DOE Nanoscale Science Research Centers (NSRC) guidance document, Approach to Nanomaterial ES&H, complies with

- Department of Energy Order 456.1A, “The Safe Handling of Unbound Engineered Nanoparticles” (DOE O 456.1A)
- ASTM International (ASTM) E2535-2007 (reapproved 2013), “Standard Guide for Handling Unbound Engineered Nanoscale Particles in Occupational Settings” (ASTM E2535-2007)

For a complete list of standards applicable to this program, see Section 8, “References”.

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3 ASTM International (ASTM) E2456-2006 (reapproved 2012), “Standard Terminology Relating to Nanotechnology” (ASTM E2456-2006)

4 Department of Energy Order 456.1A, “The Safe Handling of Unbound Engineered Nanoparticles” (DOE O 456.1A)

2 General Policy

SLAC has adopted the following policies regarding nanomaterials:

1. SLAC will comply with Department of Energy Order 456.1A, “The Safe Handling of Unbound Engineered Nanoparticles” (DOE O 456.1A), which requires the review of best practices and national consensus standards to protect workers, the public, and the environment, and sets forth requirements for
   - Maintaining a registry of all personnel who handle *unbound engineered nanoparticles (UNP)(UNP worker)* (Section 3.4.3)
   - Providing training to UNP workers and their supervisors (Section 3.7)
   - Conducting an exposure assessment and controlling exposures to UNP using a risk-based approach (Sections 3.1–3.4)
   - Offering baseline medical evaluations to UNP workers (Section 4)
   - Posting areas where UNP is used and labelling containers (Section 3.4.4)
   - Labelling containers for off-site transportation (Section 5)
   - Establishing controls for managing UNP waste (Section 6)
2. In conformance with the general principle in the National Research Council’s Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards, personnel should treat “all new compounds, or those of unknown toxicity, as though they could be acutely toxic in the short run and chronically toxic in the long run”. Moreover, although exposures to airborne nanoparticles are believed likely to be extremely low in comparison to other workplace exposures, the National Institute for Occupational Safety and Health (NIOSH) observation that all poorly soluble, low-toxicity, ultra-fine particulates might be carcinogenic, even those normally considered to be nuisance particulates, makes it important to manage carefully worker exposure and avoid environmental releases.[5]
3. Nanomaterials will be managed in a manner consistent with the known hazards and SLAC will follow a graded approach in specifying controls. The ESH coordinator will approve work for low- and medium-hazard materials. For high-hazard materials, approval will be granted either through a directorate-specific business process approved by the nanomaterial safety program manager or jointly by the nanomaterial safety program manager and ESH coordinator. (See Section 3.1, “Work Planning and Approval”, for more details.)

Implementing requirements and guidelines are described in the following sections.

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5 National Institute for Occupational Safety and Health, Current Intelligence Bulletin 63: Occupational Exposure to Titanium Dioxide (DHHS [NIOSH] Publication 2011-160), p. 6

3 Controls for Research Laboratory Operations

The following requirements are in addition to those of Chapter 40, "Chemical Lifecycle Management", and Waste Transportation", and Chapter 53, "Chemical Safety".

3.1 Work Planning and Approval

The goal of the work planning and approval process is to manage risk, which is a function of exposure and hazard (potency), to an acceptable level.[6] Since the hazard is an inherent property of the material, the risk is therefore managed by lowering the probability of exposure through controls. As such, all experiments involving nanomaterials must be categorized according to their hazard, which dictates the level of controls. The hazard level assignment is a function of the physical form of the material. (See Table 1 for details.)

- Low-hazard level (green)
  - Bound or fixed nanostructures
  - Solid materials with imbedded nanostructures
  - Solid nanomaterials with nanostructures fixed to the material's surface
- Medium-hazard level (yellow) – nanoparticles suspended in liquids
- High-hazard level (red) – dry, dispersible nanoparticles, nanoparticle agglomerates/aggregates, or nanomaterials determined to be high hazard based on safety assessment (see Section 3.1.2, "Exposure and Safety Assessment")

This categorization is performed by the researcher and confirmed by the ESH coordinator.

3.1.1 Approval

3.1.1.1 Low- and Medium-hazard

All proposed low- and/or medium-hazard nanomaterial work must be reviewed and approved by the proposer's ESH coordinator. ESH coordinator approval is normally incorporated into the directorate's approval process. Contact your ESH coordinator for details.

3.1.1.2 High-hazard

For high-hazard materials, approval will be granted either

- Through a directorate-specific business approved by the nanomaterial safety program manager, or

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6 American Industrial Hygiene Association, A Strategy for Assessing and Managing Occupational Exposures (2015)

- Jointly by the nanomaterial safety program manager and ESH coordinator. Approval will be based on draft work plans, SOPs, and other documentation.

No nanomaterial work is allowed until appropriate approval is granted.

Table 1 Control Requirements by Hazard

Hazard	Low	Medium	High
Requirements	Bound or Fixed Nanostructures	Nanoparticles Suspended in Liquids	Dry Dispersible Nanoparticles and Agglomerates (or otherwise hazardous – see Section 3.1)
Approval	ESH coordinator	ESH coordinator	Approved directorate business process, or joint nanomaterial safety program manager and ESH coordinator
PPE requirements for handling	Standard PPE required for the work area. No additional PPE is needed for this nanomaterials work.	Standard PPE required for the work area plus: ▪ Nitrile gloves or gloves appropriate for the suspension medium ▪ Eye protection: safety glasses	
Handling requirements	For work outside of HEPA-filtered containment: ▪ 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	If there is a potential for particle aerosol formation, manipulation should be done within HEPA-filtered containment over adsorbent paper to capture any spills. Solutions brought to the beam line 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).	At a minimum: ▪ Material should be manipulated within HEPA-filtered containment over dampened absorbent 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 should be completed within laboratory containment. ▪ Nanoscale materials brought to the beam line must be sealed within a sample holder, a capillary tube, or between 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 liquid scrub of the gas exhaust to provide a final barrier to particle loss.

3.1.2 Exposure and Safety Assessment

All work with nanomaterials will be reviewed for ESH concerns by their ESH coordinator. Before starting work, this assessment must be completed consistent with the following:

- Evaluate the potential for worker exposure for all activities involving nanomaterials.
- Specify hazard controls, including
  - Engineered controls
  - Design reviews
  - Formal procedures
  - Use of personal protective equipment (PPE)
  - Training
  - Other administrative controls
  - Defined criteria for work-change control
- Consider
  - All routes of possible exposure to nanomaterials, including inhalation, ingestion, injection, and dermal contact, including eye and mucous membranes
  - 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
  - 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
  - The recognized and foreseeable hazards of the precursor materials and intermediates as well as those of the resulting nanomaterials
  - The potential for reactions involving nanomaterials already captured in exhaust air filters

Involve subject matter experts (for example, industrial hygiene, industrial safety, or fire protection) as appropriate.

3.2 Control Preferences

SLAC will follow a graded approach in specifying controls. Operations involving easily dispersed dry nanomaterials deserve more attention and more stringent controls than those in which the nanomaterials are imbedded in solid or suspended in liquid matrices.

From the perspective of managing laboratory worker health, the following represents the order of preference (most preferred to least preferred) for handling nanomaterials:

1. Solid materials with imbedded nanostructures
2. Solid nanomaterials with nanostructures fixed to the material’s surface
3. Nanoparticles suspended in liquids
4. Dry, dispersible (engineered) nanoparticles, nanoparticle agglomerates, or nanoparticle aggregates

Do not handle nanomaterials in the open air in a *free particle* state. Handle and store dispersible nanomaterials, whether suspended in liquids or in a dry particle form in closed (tightly sealed) containers.

Consider the hazardous properties of the precursor materials as well as those of the resulting nanomolecular product. Remember, nanomaterial hazards might not be known or reliably anticipated.

3.3 Engineered Controls

3.3.1 Work Area Design

- Consider the potential need to implement additional engineered or procedural controls to ensure workers are protected in areas where engineered nanoparticles will be handled.
- Consider additional controls that will better ensure that engineered nanoparticles are not brought out of the work area on clothing or other surfaces. For example, install step-off pads, create a buffer area, and ensure the availability of decontamination facilities for workers.

3.3.2 Ventilation Preferences

- Conduct any work that could generate engineered nanoparticles in an enclosure that operates at a negative pressure differential compared to the worker's breathing zone. Examples of such enclosures include glove boxes, glove bags, and laboratory bench-top or floor-mounted chemical hoods. In some cases, the air reactivity of precursor materials may make it unsafe to operate in a negative pressure glove box and a positive pressure box may be used if it has passed a helium leak test. (In addition, the DOE currently requires that "enclosed systems under positive pressure must be used in a negative pressure enclosure and exhausted prior to opening" [DOE O 456.1A].) If a process (or subset of a process) cannot be enclosed, then use other engineered systems to control fugitive emissions of nanomaterials or hazardous precursors that might be released. For example, use a local exhaust system like a snorkel hood.
- Minimize the dispersal and environmental release of nanomaterials. Carry out all manipulations of engineered nanoparticles in a glove box, glove bag, chemical fume hood, or other airborne contaminant control system. Whenever feasible, remove (scrub or capture) the contaminant from the effluent from such a control system before the effluent is released into the general environment. If it is not feasible to handle dispersible nanoparticles in such a containment system, conduct and document the results of a hazards analysis before using alternative hazard controls.
- Exhaust the effluent from ventilated enclosures outside the building whenever feasible. Filters, scrubbers, or bubblers may be appropriate to treat unreacted precursors and may also be effective in reducing nanomaterial emissions. If using portable bench-top high-efficiency particulate air (HEPA) filtered units, exhaust them through ventilation systems that will carry the effluent outside the building whenever possible.
- If it is not feasible to duct HEPA-filtered treated exhaust air outside of the building:
  - Follow the guidance in ANSI/AIHA Z9.7-2007, "Recirculation of Air from Industrial Process Exhaust Systems" (ANSI/AIHA Z9.7-2007).
  - Conduct a hazards assessment and implement appropriate engineering controls. Examples of such controls include periodic air monitoring, and an accurate warning/signal capable of initiating corrective action or process shutdown before nanoparticles could be exhausted or re-entrained into the work area.

- Do not use horizontal laminar-flow hoods (*clean benches*) that direct a flow of HEPA-filtered air into the user's face for operations involving nanomaterials that might easily become entrained in the air.
- Consider exhausting Type II biological safety cabinets, in which free nanomaterials are handled, directly to the exterior (hard ducted) or through a thimble connection over the cabinet's exhaust. Air from inside the cabinet, even if HEPA-filtered, should not be recirculated within the laboratory except as provided for in ANSI/AIHA Z9.7-2007.
- Maintain and test the effectiveness of exhaust systems and components as specified by the manufacturer. Evaluate equipment previously used to synthesize, handle or capture nanoparticles for contamination and incompatibility before reusing or disposing of it.
- Evaluate equipment previously used to synthesize, handle or capture nanoparticles for contamination and incompatibility before removing, remodeling, repairing, reusing or disposing of it. Due to the potential for residual contamination, use appropriate cleaning methodologies (that is, wet wiping).

3.4 Administrative Controls

3.4.1 Housekeeping

Practice good housekeeping in laboratories where nanomaterials are handled. Follow a graded approach paying attention where dispersible nanomaterials are handled.

- Insofar as practicable, maintain all working surfaces (that is, benches, glassware, apparatus, exhaust hoods, support equipment) free of engineered nanoparticle contamination and otherwise limit worker exposure engineered nanoparticles and associated hazards.
- In areas where engineered nanoparticles might settle, perform precautionary cleaning, for example, by wiping horizontal surfaces with a moistened disposable wipe, no less frequently than at the end of each shift.
- Before selecting a cleaning method, consider the potential for complications due to the physical and chemical properties of the engineered nanoparticles, particularly in the case of larger spills. Complications could include reactions with cleaning materials and other materials in the locations where the waste will be held.[7] Such locations include vacuum cleaner filters and canisters.
- Clean up dry, engineered nanomaterials using
  - Wet wiping
  - A dedicated, approved HEPA vacuum, the filtration effectiveness of which has been verified (consider possible pyrophoric hazards associated with vacuuming up nanoparticles)
  - Other SLAC-approved methods that do not involve dry sweeping or the use of compressed air
- Dispose of used cleaning materials and wastes in accordance with Chapter 17, "Hazardous Waste". (See Section 6, "Management of Nanomaterial-bearing Waste Streams".)

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7 An exothermic reaction involving nanomaterials and wipes at a DOE facility reportedly resulted in discovery of an incipient fire in a domestic trash container.

3.4.2 Work Practices

- Transfer engineered nanomaterial samples between workstations (such as exhaust hoods, glove boxes, furnaces) in closed, labeled containers.
- Take reasonable precautions (see Section 3.5, "Clothing and Personal Protective Equipment") to minimize the likelihood of skin contact with engineered nanoparticles or nanoparticle-containing materials likely to release nanoparticles (nanostructures).
- If engineered nanoparticle powders must be handled without the use of exhaust ventilation (that is, laboratory exhaust hood, local exhaust) or enclosures (that is, glove box), evaluate hazards and implement alternative work practice controls to control potential contamination and exposure hazards.
- Handle nanomaterial-bearing waste according to Chapter 17, "Hazardous Waste", and Section 6, "Management of Nanomaterial-bearing Waste Streams".
- Vacuum dry-engineered nanoparticulates only with a HEPA vacuum cleaner that has been performance tested and certified.

3.4.3 Registry Requirements

- The ESH coordinator must maintain an electronic registry of the unbound engineered nanoparticles (UNPs) for their respective areas on the Nanomaterial Safety Team Site (SharePoint).
- At a minimum, the registry must include the name(s) of personnel who handle the UNP, job title, brief description of the UNP, brief description of the UNP activity, the area in which the activity is located, and the date the UNP was added to the registry.
- The registry must be made available to the SLAC Occupational Health Center.

3.4.4 Marking, Labeling, and Signage

- For experiments using medium- and high-hazard materials, post signs indicating the nanomaterial hazard at entry points into designated areas where dispersible, engineered nanoparticles are handled. A *designated area* may be an entire laboratory, an area of a laboratory, or a containment device such as a laboratory hood or glove box (see Figure 1).
- Where appropriate, label storage containers to indicate plainly that the contents are in engineered nanoparticulate form, for example, NANOSCALE ZINC OXIDE PARTICLES or other identifier instead of just "zinc oxide".
- When engineered nanoparticles are being moved within SLAC or off-site, follow the labeling requirements in Section 5, "Transportation of Nanomaterials".

Figure 1 Sample Laboratory Sign

3.5 Clothing and Personal Protective Equipment

- Wear appropriate PPE, including respiratory protection, on a precautionary basis whenever the failure of a single control, including an engineered control, could entail a significant exposure to researchers or support personnel. Ensuring that engineered controls (for example, laboratory chemical hoods) are equipped with performance monitors that will notify users of equipment malfunction may be considered as an alternative.
- Conduct a hazard evaluation to determine the selection and use personal protective equipment (PPE) appropriate for the level of hazard following the requirements set forth in Chemical Safety: Personal Protective Equipment Requirements, and 29 CFR 1910 Subpart I. Protective clothing that would typically be required for a wet-chemistry laboratory would be appropriate, 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)
  - Gauntlet-type gloves or nitrile gloves with extended sleeves
  - Laboratory coats

- Wear polymer (for example, nitrile rubber) gloves when handling engineered nanomaterials and particulates in liquids.[8] Choose gloves only after considering the resistance of the glove to the chemical attack by both the nanomaterial and, if suspended in liquids, the liquid.
  - Recognizing that exposure to nanomaterials is not known to have good warning properties, change gloves routinely to minimize potential exposure hazards. Alternatively, double glove.[9]
  - Keep contaminated gloves in a plastic bag or other sealed container in a hood until disposed.
  - Dispose of contaminated gloves in accordance with Section 6, "Management of Nanomaterial-bearing Waste Streams".
  - Wash hands and forearms after wearing gloves.
- Wear eye protection, for example, spectacle-type safety glasses with side shields (meeting basic impact resistance of ANSI Z87.1), face shields, chemical splash goggle, or other safety eyewear appropriate to the type and level of hazard. Do not consider face shields or safety glasses to provide sufficient protection against unbound, dry materials that could become airborne.
- Use industrial hygiene professionals or paraprofessionals working under the direction of an industrial hygiene professional to evaluate airborne exposures to engineered nanomaterials. If respirators are to be used for protection against engineered nanoparticles, select and use half-mask, P-100 cartridge-type respirators or respirators that provide a higher level of protection.
- Keep potentially contaminated clothing and PPE in the laboratory or change out area to prevent engineered nanoparticles from being transported into common areas.
- Appropriately clean and/or dispose of all potentially contaminated clothing and PPE.

3.6 Monitoring and Characterization

- When appropriate or when requested by ESH coordinators, the Industrial Hygiene group will use a direct-reading particle-measuring device to screen for suspect emissions. The results of this will determine if additional controls are needed or must be upgraded or serviced.
- The registries of the unbound engineered nanoparticles (UNPs) on the Nanomaterial Safety Team Site (SharePoint) and Occupational Health Center records will be used to link environmental data indicative of exposure to nanoparticulates with potentially exposed workers.

3.7 Worker Competency

- SLAC staff who work with nanomaterial in laboratories within the scope of this plan (nanoparticle workers and their supervisors) must complete the following:
  - ESH Course 161, Nanomaterials Laboratory Safety (ESH Course 161)

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8 When handling articles having nanomaterials in a securely bound form, that is, when protection from nanoparticles and other hazards is not needed, cotton gloves and other gloves not typically appropriate in chemical laboratories can be considered. However, steps must be taken to avoid their misuse as protective equipment.

9 Wearing an inner glove can lessen the likelihood of contaminating hands while removing a contaminated outer glove.

  - The course must be completed upon initial assignment to the laboratory. The course will define nanomaterials and provide information on how to carry out activities with nanomaterials in a safe and environmentally responsible way.

- Visiting scientists, guest researchers, and other lab users who are not SLAC employees or subcontractors must take ESH Course 161 or demonstrate that they understand applicable nanomaterial safety principles. This can be accomplished by providing acceptable proof of nanomaterial laboratory safety training from another institution or passing an exam. Contact your ESH coordinator for details.

- Specific procedural requirements will be incorporated into the laboratory safe operating procedures written and maintained by the laboratory supervisor.

4 Medical Surveillance

4.1 Worker Health Surveillance

Until a consensus emerges regarding health monitoring, the Occupational Health Center will provide the following:

- SLAC staff identified by their supervisors as UNP workers will be offered a baseline medical evaluation by enrollment in ESH Course 161ME. This baseline medical evaluation will consist of a general physical exam, including general blood work, pulmonary function test, and other tests and exams as determined by the Occupational Health Center.
- SLAC staff involved in any incident that results in an unexpected and/or unusually high exposure to nanomaterials, through any route of entry, or at the discretion of the Occupational Health doctor, will be examined by the Occupational Health Center for a post-incident evaluation per 29 CFR 1910.1450(g)(1)(i).

Non-resident personnel (for example, facility users) must satisfy the nanomaterial medical surveillance program requirements from their home organization.

The Occupational Health Center has access to the UNP registry on the Nanomaterial Safety Team Site (SharePoint) to facilitate meeting medical surveillance requirements.

5 Transportation of Nanomaterials

The transportation of nanomaterials both on- and off-site must meet the requirements of Chapter 52, "Hazardous Material and Waste Transportation", as modified by the requirements below.

5.1 Off-site Shipments

The requirements of this section apply to the movement of material to and from off-site locations.

5.1.1 Recognized Hazardous Materials

Any nanomaterial that meets the definition of a hazardous material according to 49 CFR 171.8 and can be classified as a hazardous material in accordance with 49 CFR 173.115–141 and 173.403–436 must be packaged, marked, labeled, shipping papers prepared, and shipped in accordance with Chapter 52, "Hazardous Materials and Waste Transportation" .

5.1.2 Suspected DOT Hazardous Materials

Nanomaterials that are suspected to be hazardous (for example, toxic, reactive, flammable) must be classified, labeled, marked, and manifested as though that hazard exists, in accordance with Section 5.1.1, "Recognized Hazardous Materials". These materials should be classified and shipped as samples per Department of Transportation (DOT) regulations (49 CFR 172.101c[11]) unless the material is specifically prohibited by 173.21, 173.54, 173.56(d), 173.56(e), 173.224c or 173.225(b). These suspect materials should be packaged in accordance with Section 5.1.3, "Other Nanomaterials".

5.1.3 Other Nanomaterials

Nanomaterials that do not meet the DOT criteria listed above still may pose health and safety issues to personnel handling the material if they are released during its transport. Therefore, all shipments of nanomaterials, regardless of whether they meet the definition for hazardous materials or not, should be consistently packaged and labeled as described below.

5.1.3.1 Packaging

The outer and inner package should meet the definition of a Package Group I (PG I) type package. The innermost container should be tightly sealed to prevent leakage of nanomaterials. It should have a secondary seal, such as tape seal, or a wire tie to prevent a removable closure from inadvertently opening during transport.

The outer package should be filled with shock absorbing material that can

- Protect the inner sample container(s) from damage
- Absorb liquids that might leak from the inner container(s) during normal events in transport

5.1.3.2 Labeling

As depicted in Figure 2 and Figure 3, the inner package should be labeled (not to be confused with DOT hazard labeling) as follows:

- CAUTION: NANOMATERIALS SAMPLE CONSISTING OF (technical description here) CONTACT (name of point of contact) at (contact number) in case of container breakage

If the nanomaterial is in the form of dry dispersible particles, add the following line of text:

- NANOPARTICULATES CAN EXHIBIT UNUSUAL REACTIVITY AND TOXICITY. AVOID BREATHING DUST, INGESTION, AND SKIN CONTACT".

Documentation and notifications for off-site transfer of nanomaterials should include the following:

- A signed and complete dangerous goods declaration or shipping papers prepared in accordance with the International Civil Aviation Organization (ICAO) and DOT regulations by certified/qualified hazmat employees who are authorized to release materials from the site.
- Available descriptions of the material, for example, safety data sheets (SDSs). (With respect to samples researchers should prepare a document that describes known properties and other properties that deem reasonably likely to be exhibited by samples.)
- A notification to receiving facility of the incoming shipment.

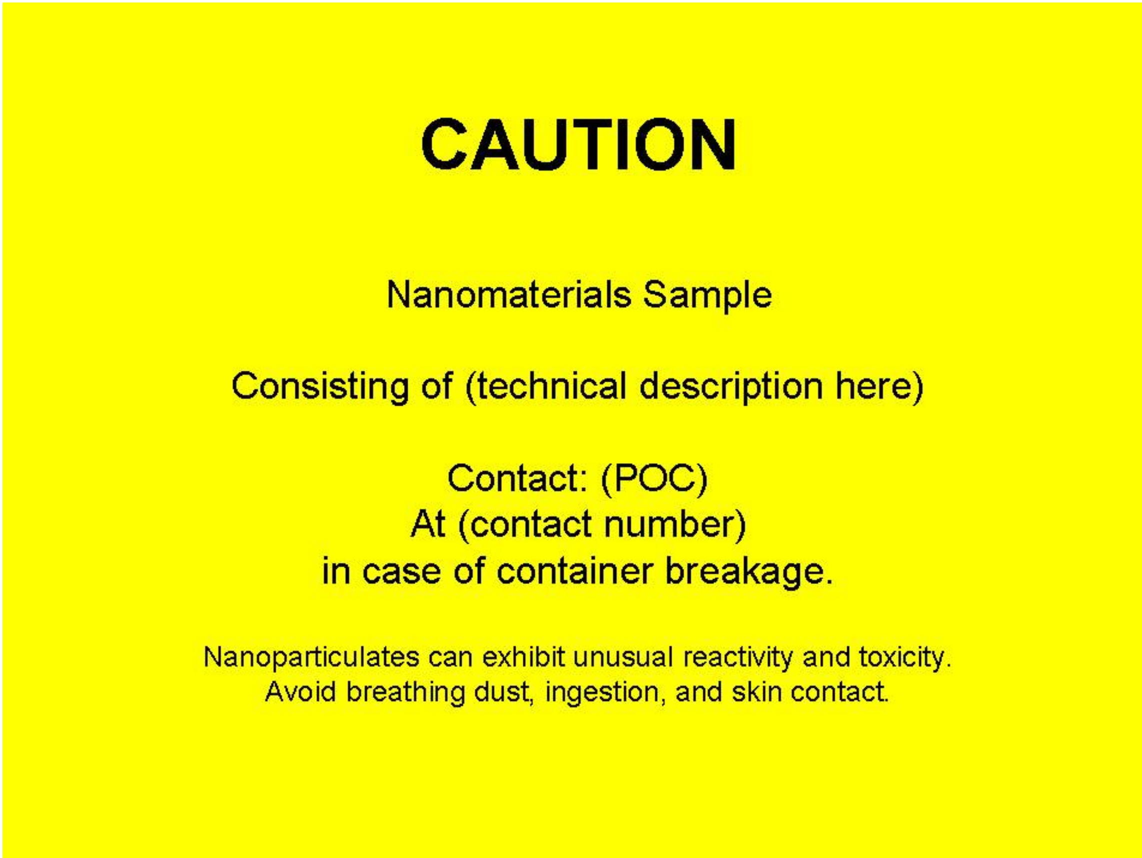

Figure 2 Inner Packaging Label for Dry Particulates

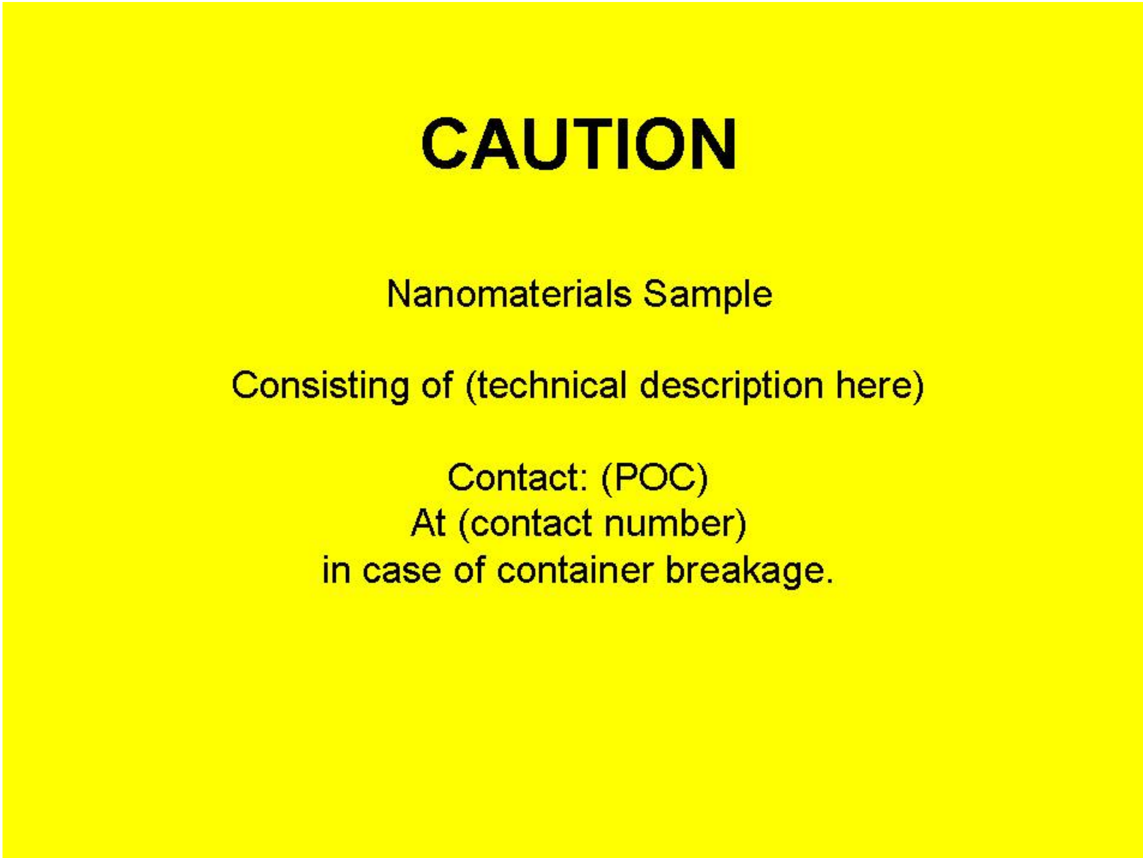

Figure 3 Inner Packaging Label for Non-particulates

5.1.3.3 Modes of Transport

All materials should be transported by a qualified carrier, for which the DOE or the General Services Administration (GSA) has a tender on file. All transportation services must comply with the Federal Acquisition Regulations (FAR).[10] Recommended modes for off-site shipment of nanomaterials include

- FedEx, or other certified hazardous-materials carrier
- Roadway, UPS Ground, or other commercial less-than-truckload (LTL)-certified hazardous-materials carrier
- Dedicated highway hazardous-materials carriers for exclusive-use shipments using a carrier approved by the DOE Motor Carrier Evaluation Program (MCEP)
- Shipments of nanomaterials classified as *other materials* (neither recognized hazardous materials or suspected DOT hazardous materials) may be transported using the most expeditious method provided they are packaged per the requirements in Section 5.1.3.1, “Packaging”, and the following conditions are met:

10 Title 48, *Code of Federal Regulations*, “Federal Acquisition Regulations System” (48 CFR)

- The driver must have a valid state driver's license appropriate for the vehicle being operated.
- The vehicle must be in good mechanical condition and have a valid state safety inspection.
- The vehicle must be insured with at least the required minimum liability insurance required by the state where the vehicle is registered.
- The driver must obey all state and local traffic rules and regulations.
- The driver must possess basic hazard information on the commodity being transported, that is, material name, quantity, form and safety data sheet if available.

5.2 On-site Transfers of Nanomaterials

The on-site transfer of nanomaterials must follow the requirements in Hazardous Materials and Waste Transportation: On-site Transportation Requirements. For nanomaterials, add the following:

- Assess and record the hazards posed by the material(s) following a graded approach that takes into account the form of the material(s) (for example, free particle versus fixed on substrate).
- Use packaging consistent with the recommendations for off-site shipment or packaging that affords an equivalent level of safety.
- Mark the transfer containers in accordance with the (above) recommendations for off-site shipments.
- Include the following documents in the package:
  - The results of the safety assessment
  - An SDS, if available, or a similar form detailing possible hazards associated with the material; otherwise, if an SDS is unavailable, the principal investigator should supply material-specific knowledge
- Notify the receiving facility of the incoming shipment.

6 Management of Nanomaterial-bearing Waste Streams

6.1 Applicability

The following waste management requirements, in addition to those of Chapter 17, “Hazardous Waste”, apply to nanomaterial-bearing waste streams consisting of

- Nanomaterials (for example, carbon nanotubes)
- Items contaminated with nanomaterials (for example, wipes and PPE)
- Liquid suspensions containing nanomaterials (for example, hydrochloric acid containing carbon nanotubes)
- Hazardous solids containing or coated with nanomaterials that can be released into the air or leach into liquids. This includes nanomaterials that can be dislodged via mechanical forces, such as scraping.

The requirements do 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.

6.2 Nanomaterials in Waste Streams

- Consider any material that has come into contact with dispersible engineered nanoparticles (that has not been decontaminated) as belonging to a nanomaterial-bearing waste stream. This includes PPE, wipes, blotters, and other disposable laboratory materials used during research activities.
- In order to reduce waste generated, consider reducing the risk of loss of nanomaterials into the air and surrounding environment by suspending powders in a small volume of a non-hazardous liquid. Balance the added safety, if any, against the risks and costs of the increased volume of waste.
- Evaluate surface contamination or decontaminate equipment used to manufacture or handle nanoparticles before disposing of or reusing it. Treat wastes (cleaning solutions, rinse waters, rags, and PPE) resulting from decontamination as nanomaterial-bearing waste.

6.3 Classification and Disposal of Nanomaterial-bearing Waste Streams

- Do not put material from nanomaterial-bearing waste streams into to the regular trash or down the drain.
- Do not permit nanomaterial-bearing wastes to be shipped off-site to researchers’ home institutions for disposal.
- Characterize and manage nonmaterial-bearing waste streams as either hazardous or non-hazardous waste based on the requirements in 40 CFR 261.10–38, or equivalent state regulations, considering their known characteristics and/or listing of the waste.

- Package nanomaterial-bearing wastes in containers that are compatible with the contents, in good condition, and that afford adequate containment to prevent the escape of the nanomaterials.
- To the extent possible, segregate nanomaterial waste from other waste during management and disposition.
- Label the waste container with a description of the waste and the words CONTAINS NANOMATERIALS. Include available information characterizing known and suspected properties.
- Collect paper, wipes, PPE and other items with loose contamination in a plastic bag or other sealing container stored in the laboratory hood. When the bag is full, close it, take it out of the hood and place it into a second plastic bag or other sealing container. Label the outer bag with the laboratory’s proper waste label.
- Keep an inventory record of all nanomaterial waste that is shipped off-site; the inventory will maintain a description of the waste, the quantity, and means and location of final disposition.

7 Management of Nanomaterial Spills

The following requirements are in addition to those of Chapter 16, “Spills”.

7.1 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 to restrict entry into the area.
- Refer personnel exposed to nanomaterials in the course of a spill to the Occupational Health Center.

7.2 Dry Materials

- Position a walk-off mat where cleanup personnel will exit the access-controlled area to reduce the likelihood of spreading nanoparticles.
- Clean using wet-wiping methods. Characterize, collect, and dispose of spill cleanup materials as nanomaterial-bearing waste. (See Section 6, “Management of Nanomaterial-bearing Waste Streams”.)
- Use a tested and certified HEPA vacuum; do not use dry sweeping or compressed air.
  - Ensure that the effectiveness of HEPA filters is verified at a frequency consistent with manufacturer recommendations.
  - When feasible, use only dedicated HEPA vacuums used for nanomaterial cleanup. Label the units accordingly, for example, USE ONLY FOR NANOMATERIAL SPILL CLEANUP. Log the type of material collected and avoid mixing potentially incompatible materials in the vacuum or filters.
  - Characterize, collect, and dispose of used HEPA filters as nanomaterial-bearing waste.
  - Consider the possible air reactivity of nanoparticles prior to using a vacuum cleaner. Some normally stable powders may become pyrophoric if deposited on a filter and subject to high airflow.

7.3 Liquids

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

- Position an absorbent walk-off mat where the cleanup personnel will exit the access-controlled area to prevent the spread of liquids containing suspended nanoparticles.
- Place barriers (for example, plastic sheeting) that will minimize air currents across the surface affected by the spill.
- Use a wet-wiping method to clean the spill. A HEPA-filtered vacuum dedicated to the cleanup of nanomaterials may also be used to clean up residual nanomaterials left behind after the spill area has dried.

- Manage all materials used to clean up the spill (such as absorbent mats, absorbent material, wipes) as hazardous or potentially hazardous waste based on the material involved.

7.4 Wastes

- Manage all debris resulting from the cleanup of a spill as though it contains sufficient nanomaterials to be managed in accordance with Section 6, “Management of Nanomaterial-bearing Waste Streams”.

8 References

The following are documents referred to by or related to this plan.

Table 2 References

Title	Document Number	Originating Unit	URL
Nanomaterial Safety Team Site (SharePoint)		FS	https://portal.slac.stanford.edu/teams/esh/nano/SitePages/Home.aspx
Environment, Safety, and Health Manual Chapters			
Chapter 16, "Spills"	SLAC-I-720-0A29Z-001	FS	http://www-group.slac.stanford.edu/esh/environment/spills/
Chapter 17, "Hazardous Waste"	SLAC-I-720-0A29Z-001	FS	http://www-group.slac.stanford.edu/esh/environment/hazardous_waste
Chapter 40, "Chemical Lifecycle Management"	SLAC-I-720-0A29Z-001	FS	http://www-group.slac.stanford.edu/esh/hazardous_substances/chemmanage/
Chapter 52, "Hazardous Material and Waste Transportation"	SLAC-I-720-0A29Z-001	FS	http://www-group.slac.stanford.edu/esh/hazardous_substances/hazmattransport/
Hazardous Materials and Waste Transportation: On-site Transportation Requirements	SLAC-I-730-0A09S-037	FS	http://www-group.slac.stanford.edu/esh/eshmanual/references/hazmattransportReqOnsite.pdf
Chapter 53, "Chemical Safety"	SLAC-I-720-0A29Z-001	FS	http://www-group.slac.stanford.edu/esh/hazardous_substances/chemsafety/
Chemical Safety: Personal Protective Equipment Requirements	SLAC-I-730-0A09S-017	FS	http://www-group.slac.stanford.edu/esh/eshmanual/references/chemsafetyReqPPE.pdf
ESH Other			
Hazard Communication and MSDS References		FS	http://www-group.slac.stanford.edu/esh/groups/fsd/hmaq/hazmat/hazcom.htm
SLAC Occupational Health Center		OHC	http://www-group.slac.stanford.edu/esh/medical/
ESH Course 161, Nanomaterials	ESH Course	FS	https://www-

Title	Document Number	Originating Unit	URL
Laboratory Safety	161		internal.slac.stanford.edu/esh-db/training/slaconly/bin/catalog_item.asp?course=161
ESH Course 161ME, Medical Surveillance for Nanoparticle Workers	ESH Course 161ME	FS	https://www-internal.slac.stanford.edu/esh-db/training/slaconly/bin/catalog_item.asp?course=161ME
Safety Coordinators		ESH	http://www-group.slac.stanford.edu/esh/groups/safety_coordinators/
SLAC Other			
SLAC eShipper		Purchasing	https://www-bis1.slac.stanford.edu/eShipper/mypage.aspx
External Requirements			
Department of Energy Order 456.1A, "The Safe Handling of Unbound Engineered Nanoparticles"	DOE O 456.1A	United States Department of Energy	https://slacspace.slac.stanford.edu/sites/ipm/requirementsmanagement/DOEDirectives/default.aspx
Title 29, *Code of Federal Regulations*, "Labor", Subtitle B, "Regulations Relating to Labor (Continued)", Chapter 17, "Occupational Safety and Health Administration, Department of Labor", Part 1910, "Occupational Safety and Health Standards", Subpart I, "Personal Protective Equipment"	29 CFR 1910 Subpart I	United States	https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10118
Title 29, *Code of Federal Regulations*, "Labor", Subtitle B, "Regulations Relating to Labor (Continued)", Chapter 17, "Occupational Safety and Health Administration, Department of Labor", Part 1910, "Occupational Safety and Health Standards", Subpart Z, "Toxic and Hazardous Substances", Section 1450, "Occupational Exposure to Hazardous Chemicals in Laboratories"	29 CFR 1910.1450(g)(1)(i)	United States	https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10106
Title 40, *Code of Federal Regulations*, "Protection of the Environment", Chapter 1, "Environmental Protection Agency", Subchapter I, "Solid Wastes", Part 261, "Identification and Listing of Hazardous Waste", Sections 10 through 38	40 CFR 261.10–38	United States	https://www.ecfr.gov/cgi-bin/text-idx?SID=831f26fdbbec5b67f3b4dc31d2a1ac9b&mc=true&node=pt40.26.261&rgn=div5
Title 48, *Code of Federal Regulations*, "Federal Acquisition Regulations System"	48 CFR	United States	https://www.ecfr.gov/cgi-bin/text-idx?SID=7e2973cacbfc84850fee5420

Title	Document Number	Originating Unit	URL
			820cad1d&mc=true&tpl=/ecfrbrowse/Title48/48tab_02.tpl
Title 49, *Code of Federal Regulations*, "Transportation", Subtitle B, "Other Regulations Relating to Transportation", Chapter 1, "Pipeline and Hazardous Materials Safety Administration, Department of Transportation"	49 CFR 100–185	United States	https://www.ecfr.gov/cgi-bin/text-idx?gp=&SID=7e2973cacbfc84850fee5420820cad1d&mc=true&tpl=/ecfrbrowse/Title49/49chapterI.tpl
Title 49, *Code of Federal Regulations*, "Transportation", Subtitle B, "Other Regulations Relating to Transportation", Chapter 1, "Pipeline and Hazardous Materials Safety Administration, Department of Transportation", Subchapter C, "Hazardous Materials Regulations", Part 171, "General Information, Regulations, and Definitions", Subpart A, "Applicability, General Requirements, and North American Shipments", Section 8, "Definitions and Abbreviations"	49 CFR 171.8	United States	https://www.ecfr.gov/cgi-bin/text-idx?SID=f2c0bdde25207a03a7a608e6bbcd2e7c&mc=true&node=se49.2.171_18&rgn=div8
Title 49, *Code of Federal Regulations*, "Transportation", Subtitle B, "Other Regulations Relating to Transportation", Chapter 1, "Pipeline and Hazardous Materials Safety Administration, Department of Transportation", Subchapter C, "Hazardous Materials Regulations", Part 172, "Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information, and Training Requirements", Subpart H, "Training"	49 CFR 172 Subpart H	United States	https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=19a99fe27b3f03f237dff3906cac5065&mc=true&n=pt49.2.172&r=PART&ty=HTML#sp49.2.172.h
Title 49, *Code of Federal Regulations*, "Transportation", Subtitle B, "Other Regulations Relating to Transportation", Chapter 1, "Pipeline and Hazardous Materials Safety Administration, Department of Transportation", Subchapter C, "Hazardous Materials Regulations", Part 172, "Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information, and Training Requirements", Subpart B, "Table of Hazardous Materials and Special Provisions", Section 101, "Purpose and Use of Hazardous Materials Table"	49 CFR 172.101c(11)	United States	https://www.ecfr.gov/cgi-bin/text-idx?SID=7e2973cacbfc84850fee5420820cad1d&mc=true&node=se49.2.172_1101&rgn=div8

Title	Document Number	Originating Unit	URL
Title 49, *Code of Federal Regulations*, “Transportation”, Subtitle B, “Other Regulations Relating to Transportation”, Chapter 1, “Pipeline and Hazardous Materials Safety Administration, Department of Transportation”, Subchapter C, “Hazardous Materials Regulations”, Part 173, “Shippers–General Requirements for Shipments and Packagings”, Subpart D, “Definitions Classification, Packing Group Assignments and Exceptions for Hazardous Materials Other Than Class 1 and Class 7”, sections 115 through 141	49 CFR 173.115–141	United States	https://www.ecfr.gov/cgi-bin/text-idx?SID=7e2973cacbfc84850fee5420820cad1d&mc=true&node=pt49.2.173&rgn=div5#se49.2.173_1115
Title 49, *Code of Federal Regulations*, “Transportation”, Subtitle B, “Other Regulations Relating to Transportation”, Chapter 1, “Pipeline and Hazardous Materials Safety Administration, Department of Transportation”, Subchapter C, “Hazardous Materials Regulations”, Part 173, “Shippers–General Requirements for Shipments and Packagings”, Subpart I, “Class 7 (Radioactive) Materials”, sections 403 through 436	49 CFR 173.403–436	United States	https://www.ecfr.gov/cgi-bin/text-idx?SID=7e2973cacbfc84850fee5420820cad1d&mc=true&node=pt49.2.173&rgn=div5#sp49.2.173.i
International Civil Aviation Organization (ICAO) Technical Instructions for the Safe Transport of Dangerous Goods by Air	ICAO Document 9284	International Civil Aviation Organization	http://www.icao.int/publications/pages/publication.aspx?docnum=9284
American National Standards Institute/American Industrial Hygiene Association (ANSI/AIHA) Z9.7-2007, “Recirculation of Air from Industrial Process Exhaust Systems”	ANSI/AIHA Z9.7-2007	American National Standards Institute/American Industrial Hygiene Association	http://www.slac.stanford.edu/spires/find/libresource/wwwesh?s=ANSI_Z9.7_2007
American National Standards Institute (ANSI) Z87.1, "Occupational and Educational Personal Eye and Face Protection Devices"	ANSI Z87.1	American National Standards Institute	http://www.slac.stanford.edu/spires/find/libresource/wwwesh?s=ANSI_Z87.1
ASTM International (ASTM) E2456-2006, “Standard Terminology Relating to Nanotechnology” (reapproved 2012)	ASTM E2456-2006	ASTM International	http://www.slac.stanford.edu/spires/find/libresource/wwwesh?s=ASTM_E2456_2006
ASTM International (ASTM) E2535-2007, “Standard Guide for Handling Unbound Engineered Nanoscale Particles in Occupational Settings” (reapproved 2013)	ASTM E2535-2007	ASTM International	http://www.slac.stanford.edu/spires/find/libresource/wwwesh?s=ASTM_E2535_2007
External Guidelines / References			
Approach to Nanomaterial ES&H	Revision 3a	United States	https://science.energy.gov/~/media/be

Title	Document Number	Originating Unit	URL
		Department of Energy, Nanoscale Science Research Centers	s/pdf/doe_nsrc_approach_to_nanomaterial_esh.pdf
Approaches to Safe Nanotechnology: Managing the Health and Safety Concerns Associated with Engineered Nanomaterials	DHHS (NIOSH) Publication 2009-125	National Institute for Occupational Safety and Health	https://www.cdc.gov/niosh/docs/2009-125/
Current Intelligence Bulletin 63: Occupational Exposure to Titanium Dioxide	DHHS (NIOSH) Publication 2011-160	National Institute for Occupational Safety and Health	https://www.cdc.gov/niosh/docs/2011-160/
Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards	2011	National Research Council	https://www.nap.edu/catalog/12654/prudent-practices-in-the-laboratory-handling-and-management-of-chemical
A Strategy for Assessing and Managing Occupational Exposures	4th edition, 2015	American Industrial Hygiene Association	https://www.aiha.org/marketplace/Pages/Product-Detail.aspx?productid=%7bE255A781-74F2-E411-A28B-005056B20848%7d