


UNIVERSITY OF CALIFORNIA
Santa Barbara

CERNS: A Condensed EH&S Reference for Nanotechnology Startups

A Group Project submitted in partial satisfaction of the requirements for the degree of
Master's in Environmental Science and Management
for the
Donald Bren School of Environmental Science and Management

by

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The mission of the Bren School of Environmental Science & Management is to produce professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principal of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

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Abstract

The nanotechnology field has experienced impressive growth, which is projected to increase into the future. Concurrently, there are uncertainties surrounding the toxicity of nanomaterials, potentially creating hazards for people who are at risk of being directly or indirectly exposed. Once nanomaterials are embedded into products, the extent to which nanomaterials have the ability to be released into the environment is also unknown. Currently, there are no nanotechnology-specific regulations that require industry to adhere to certain rules regarding nano-specific environmental health and safety (EH&S). Nano-specific EH&S programs are voluntary, and require industry to independently seek guidance and resources. This task has the potential to be overwhelming to a small nanotechnology startup because of the diversity of guidance documents available, varying widely in scope, specificity, and target audience. To respond to the emerging needs of nanotechnology startups, a condensed user guide, CERNS, was developed with the intent of being both readily accessible and easy to understand. The compilation of source materials for CERNS involved extracting and consolidating information from dozens of nano-specific guidance documents and literature. CERNS also includes a cost assessment to provide startups with a framework for the recommended capital necessary to establish nano-specific EH&S. Condensing the information into an easily accessible document encourages nanotechnology startups to voluntarily implement a nano-specific EH&S program to protect their workers and the environment.

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Acronyms

AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute
BSC	Biosafety Cabinet
BSI	British Standards Institute
CAA	Clean Air Act
CERNS	A Condensed EH&S Reference for Nanotechnology Startups
CNMS	Center for Nanophase Materials Sciences
CNT	Carbon Nano Tube
CPC	Condensation Particle Counter
DOE	United States Department of Energy
ED	The Environmental Defense
EH&S	Environmental Health and Safety
ENM	Engineered Nanomaterial
ENP	Engineered Nanoparticle
EU	European Union
FHSA	Federal Hazardous Substances Act
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GEV	General Exhaust Ventilation
HEPA	High-Efficiency Particulate-Absorbing
HVAC	Heating, Ventilating, and Air-Conditioning
ICON	International Council on Nanotechnology
IRSST	Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail
ISO	International Organization for Standardization
LBNL	Lawrence Berkeley National Laboratory
LEV	Local Exhaust Ventilation
MSDS	Material Safety Data Sheet
NEAT	Nanoparticle Emission Assessment Technique
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NM	Nanomaterial
OHS	Occupational Health and Safety
OPC	Optical Particle Counter
OSHA	Occupational Safety and Health Administration
PBZ	Personal Breathing Zone
PCMNP	Products Containing Manufactured Nanoparticles
PPE	Personal Protective Equipment
RCRA	Resource Conservation and Recovery Act
REACH	Registration, Evaluation, Authorisation, and Restriction of Chemical Substances
SEM	Scanning Electron Microscopy
SLAC	Stanford Linear Accelerator Center

SWCNT	Single Walled Carbon Nanotubes
TEM	Transmission Electron Microscopy
TiO ₂	Titanium Dioxide
TSCA	Toxic Substances Control Act
UC CEIN	University of California, Center for Environmental Implications of Nanotechnology
ULPA	Ultra Low Particulate Air
US EPA	United States Environmental Protection Agency
US FDA	United States Food and Drug Administration
UV	Ultraviolet

Guidance Documents

Guidance documents are reports that are intended to aid the reader in appropriately protecting themselves from any risks associated with handling and exposure of a material. The following guidance documents focus on nanotechnology specific environmental health and safety (EH&S) protection. The documents have been categorized based on their source type.

Documents from Academia

- [In Press] Center for High-Rate Nanomanufacturing: Safe Practices for Working with Engineered Nanomaterials in Research Laboratories (Ellenbecker & Tsai, 2011)
- Duke: Working Safely with Nanomaterials in the Laboratory (Duke University)
- Harvard University: Working Safely with Nanomaterials (Harvard University)
- Journal of Occupational and Environmental Hygiene: Nanoparticle Usage and Protection Measures in the Manufacturing Industry - A Representative Survey (Schmid, Danuser, & Riediker, 2010)
- Lawrence Berkeley National Laboratory: Control Procedures for Engineered Nanomaterials (Lawrence Berkeley National Laboratory, 2010)
- Massachusetts Institute of Technology: EHS Nanomaterials (Massachusetts Institute of Technology)
- Stanford University: General Principles and Practices for Working Safely with Engineered Nanomaterials (Stanford University, 2009)
- University of California Lab Safety Work Group: Nanotechnology: Guidelines for Safe Research Practices (University of California)
- University of California, Irvine: Standard Operating Procedure for Working with Carbon Nanotubes (CNT) (University of California - Irvine)
- University of California, Los Angeles: Safe Handling of Dry Carbon Nanotube Powder (Jennerjohn, Eiguren-Fernandez, & Kennedy)
- University of California, Santa Barbara: Engineered Nanomaterials: Guidelines for Safe Research Practices (University of California - Santa Barbara)
- University of New Hampshire: Nanomaterials Safety Program (University of New Hampshire, 2009)
- University of North Carolina: Summary of Recommended Nanomaterial Risk Levels (University of North Carolina)
- University of Washington: Guidelines for Safety During Nanoparticle Research (University of Washington, 2010)

Documents from Industry

- DuPont: Nano Risk Framework (Environmental Defense-DuPont Nano Partnership, 2007)

Documents from Government

- British Standards Institute: Guidance on the Labelling of Manufactured Nanoparticles and Products Containing Manufactured Nanoparticles (British Standards Institution, 2007a)
- British Standards Institute: Nanotechnologies - Part 2: Guide to Safe Handling and Disposal of Manufactured Nanomaterials (British Standards Institution, 2007b)
- Commission of the European Communities: Regulatory Aspects of Nanomaterials (Commission of the European Communities, 2008)
- Department of Energy Notice: The Safe Handling of Unbound Engineered Nanoparticles (Department of Energy, 2009)
- Department of Energy: Approach to Nanomaterial ES&H (Department of Energy, 2008)
- Department of Energy: Secretarial Policy Statement on Nanoscale Safety (Department of Energy, 2005)
- European Risk Observatory Literature Review: Workplace Exposure to Nanoparticles (Kaluza et al.)
- National Institute of Occupational Safety & Health: Current Intelligence Bulletin 60 - Interim Guidance for Medical Screening and Hazard Surveillance for Workers Potentially Exposed to Engineered Nanoparticles (National Institute for Occupational Safety and Health, 2009)
- National Institute of Occupational Safety and Health: Approaches to Safe Nanotechnology (NIOSH, 2009)
- Scientific Committee on Emerging and Newly Identified Health Risks: The Appropriateness of Existing Methodologies to Assess the Potential Risk Associated with Engineered and Adventitious Products of Nanotechnologies (Scientific Committee on Emerging and Newly Identified Health Risks, 2006)
- Stanford Linear Accelerator Center: Nanomaterial Safety Plan (Stanford Linear Accelerator Center, 2009)

Documents from Non-Profit Organizations

- Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail: Engineered Nanoparticles - Current Knowledge about OHS Risks and Prevention Measures (Ostiguy, Roberge, Woods, & Soucy, 2010)

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1. Introduction

The nanotechnology industry is rapidly growing worldwide. Lux Research (2011) estimates that products containing nanomaterials will amount to \$2.5 trillion in worth by 2015 (Fig. 1), which was recently recession-adjusted from \$3.1 trillion (Hwang & Bradley, 2010). While estimates of the net worth of nanotechnology can vary throughout the literature, there is a general consensus that growth in the nanotechnology industry shows no signs of slowing down.

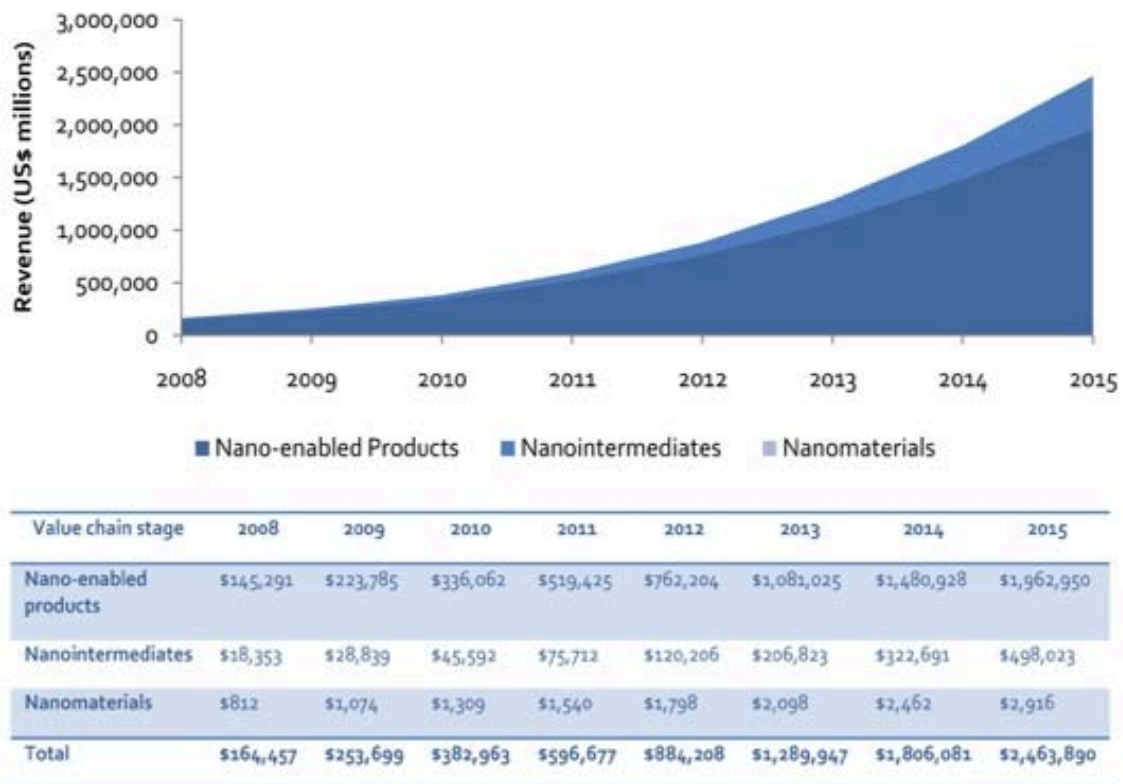


Figure 1. Nanotechnology industry growth projections Source: Lux Research (Bradley, 2010)

The term “nanotechnology” is a term used to describe applications and products that derive from manufacturing and properties at the scale of a nanometer, or one billionth of a meter (Fiorino, 2010). However, there is no complete understanding or agreement on the dimensions at which materials exhibit novel properties that impact environmental, health and safety risks. The National Nanotechnology Initiative (NNI) defines nanotechnology as “the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications” (National Nanotechnology Initiative, 2009). As matter gets smaller, it can be manipulated to make products that are comparatively faster, lighter and affordable (National Nanotechnology Initiative). Nanomaterials are currently in products including

baseball bats, plastics, eyeglasses, and cameras (National Nanotechnology Initiative). They are also found in products that could benefit the environment, including water purification systems, solar panels, and lighter cars that require less fuel (National Nanotechnology Initiative).

As with the advent of most technologies, there is a dearth of information about nanotechnology including the physicochemical properties of nanomaterials as well as their potential impacts on human health and the environment. The pace of growth is exceeding our preparedness for any adverse effects.

2. Project Significance

Many guidance documents for EH&S in the nanotechnology industry have been published from diverse sources to encourage the nanotechnology industry to implement a nano-specific EH&S program. Different sectors, including academia, government, industry, and non-profit, have independently published their own documents in support of nano-specific EH&S. Despite widespread availability, there are two main issues we identified through review of current guidance documents:

1. A cross-comparison of specific recommendations that are contained in the guidance documents has not been performed.
2. The multitude of guidance documents available could potentially be overwhelming to a company that wants to start a nano-specific EH&S program.

To address the first issue, specific recommendations were extracted from 27 guidance documents to reveal what exactly is being recommended. This was the first cross-comparison of its kind to be performed. The comparison was useful for identifying weaknesses and/or discrepancies of recommendations contained in guidance documents, as well as where further research is needed.

Our goal was to provide companies with a list of currently available guidance documents, and condense to the recommendations contained in them into one easily accessible guide. The cross-comparison allowed us to note the most frequent recommendations and to provide a condensed guide of those recommendations, allowing companies to quickly review what is currently available to them. The product was titled: “A Condensed EH&S Reference for Nanotechnology Startups (CERNS)”. CERNS would decrease the amount of time companies would have to spend researching nano-specific guidance and thus to further encourage them to implement a nano-specific EH&S program. We attained our goals through a cross-comparison of guidance documents and creation of CERNS.

3. Background Information

3.1 Ecotoxicology and Human Health Risks

An exposure route is the path by which nanomaterials enter various receptors (Oberdorster et al., 2005). Environmental exposure routes can be through wastewater, fugitive emissions, product degradation and solid waste disposal. Likewise, human exposure routes in the workplace, on the focus of this research, include through respiration and dermal contact, and possibly ingestion. Maynard *et al.* published a report in 2006 that supported the need for further assessment of the risks associated with products containing nanomaterials (Maynard et al., 2006). The following examples reveal some nanomaterial exposure routes that have had negative outcomes.

In 2008, Poland *et al.* published results from a scientific study, which revealed that carbon nanotubes (CNTs) cause asbestos-like effects when injected into mice, leading to mesothelioma (Poland et al., 2008). In 2009, Song *et al.* published a report of toxic effects of seven female workers who handled nanomaterials, two of which died (Song, Li, & Du, 2009). During hospitalization, it was revealed that prolonged and unprotected exposure to nanomaterials was likely to blame (Song, et al., 2009). These two reports are extreme examples of evidence for possible harm from human exposure to nanomaterials.

Additionally, nanomaterials in consumer products are possibly finding their way into the environment, posing vulnerabilities for terrestrial and marine organisms (Klaine et al., 2008). For example, in 2010, Goyal et al. published results of a scientific study regarding the effects of single walled carbon nanotubes (SWCNTs) on the bacterial communities in activated sludge, showing that community changes occur (Goyal, Zhang, & Rooney-Varga, 2010). These examples are just a few of the many potential negative effects of exposure to nanomaterials.

3.2 Current and Potential Regulations in the US

In order to understand the development of nanotechnology EH&S practices, it is necessary to understand how nanomaterials are currently regulated in the US, and what may happen in the future. The following federal agencies have a responsibility when it comes to nanotechnology:

- United States Environmental Protection Agency (US EPA)
- United States Food and Drug Administration (US FDA)
- Occupational Safety and Health Administration (OSHA)
- National Institute for Occupational Safety and Health (NIOSH)

The US EPA, US FDA, and OSHA have regulatory authority. OSHA has responsibility to ensure a safe workplace by enforcing standards, and they currently require EH&S but

not nano-specific EH&S. NIOSH is not a regulatory body but is responsible for conducting research and making recommendations for the prevention of work-related injury and illness. NIOSH has written a guidance document with nano-specific EH&S recommendations. Because there are currently no nano-specific regulations in the United States, in order to accomplish these missions the US EPA, US FDA, and OSHA must use other legal mechanisms embedded in existing environmental statutes.

3.2.1 Current Regulations

3.2.1.1 Toxic Substances Control Act (TSCA)

TSCA regulates new and existing chemicals on the market. While there is no reference to nanomaterials (NMs) in TSCA, the US EPA has used TSCA to regulate over 100 NMs as new chemical substances based on their differences in physical form and novel uses and applications (U.S. Environmental Protection Agency). Firms that intend to manufacture NMs for commercial use are required to submit a pre-manufacture notice (PMN) to the EPA's Office of Chemical Safety and Pollution Prevention (OCSPP) (U.S. Environmental Protection Agency). The information provided by the company in the PMN includes occupational health and safety practices, consumer product safety testing and other relevant information that the EPA will use in health and safety assessments. Approval for manufacture can then be conditionally granted after the EPA completes a risk assessment. Based on the results of this risk assessment, conditional approval may be granted to the company to manufacture their NM. Conditions may include limiting the use of the NMs, requiring the use of personal protective equipment, limiting release into the environment, proper disposal, and/or requiring further testing.

3.2.1.2 Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)

FIFRA is used to regulate the distribution and use of pesticides in the United States (Owens, 2009). The EPA defines a pesticide as “any substance or mixture of substance intended for preventing, destroying, repelling, or mitigating any pest”, and as such, FIFRA regulations pertain to herbicides, nematocides, insecticides, larvicides, fungicides, rodenticides, antimicrobial compounds not regulated by the US FDA, and some swimming pool sanitization chemicals (U.S. Environmental Protection Agency, 2011b). Any firm wishing to sell a pesticide must apply to register their product with the EPA. In 2008, the US EPA required registration of silver nanoparticles as pesticides under FIFRA, based on a 2007 case where a washing machine was found to cover loads of laundry with silver nanoparticles after each wash (Ostiguy, et al., 2010). As a result of this case, FIFRA is now used to regulate, and requires registration of, any NMs that fit the EPA's definition of a pesticide.

3.2.1.3 Clean Air Act (CAA)

The Clean Air Act (CAA) gives the EPA authority to regulate fuel additives that may pose a human health risk from their emissions to air (U.S. Environmental Protection Agency, 2011a). The CAA requires new fuel additives to be registered with the US EPA and, as with TSCA and FIFRA, manufacturers and producers are required to submit data necessary for risk assessments. Therefore, the CAA can be used to regulate NMs that are present in fuel additives. One NM-based fuel additive is currently on the list of registered diesel additives (U.S. Environmental Protection Agency). It is important to note that small businesses with revenues of less than \$10 million are exempt from submitting both a literature review of known health effects and animal testing for toxicity under the CAA (U.S. Environmental Protection Agency, 2011a). This is known as a small business exemption and applies to many nanotechnology startup companies.

3.2.2 Possible Future Regulations

3.2.2.1 Possible Nano-Specific EH&S

OSHA and NIOSH work collectively to promote a safe workplace. OSHA serves as the regulatory arm while NIOSH conducts research and makes recommendations, which support OSHA. OSHA has the authority to use NIOSH's findings to enforce standards. Despite NIOSH's release of "Approaches to Safe Nanotechnology: Managing the Health and Safety Concerns Associated with Engineered Nanomaterials", in which they make nano-specific EH&S recommendations, OSHA does not currently require nanotechnology firms to have nano-specific EH&S programs (NIOSH, 2009). In the event that more toxicology data is available and NIOSH's nano-specific regulations become standards enforced by OSHA, it is imperative that firms are proactive and prepared.

3.2.2.2 Possible TSCA Reform

The United States Environmental Protection Agency (EPA) has been regulating new nanoscale materials as novel chemical substances by utilizing authorities granted under TSCA (U.S. Environmental Protection Agency, 2010). Despite there being no reference to NMs in TSCA, the EPA has been able to classify NMs as new chemical substances based on their differences in physical form and their new uses and applications (U.S. Environmental Protection Agency, 2010). On July 22, 2010, the TSCA Reform Bill (H.R. 5820) was introduced to the House of Representatives in an effort to revamp TSCA (Hogue, 2010). TSCA reform would require manufacturers and producers of chemicals to disclose more data, and would also make it easier for the EPA to ban chemicals that cause unreasonable risk (Hogue, 2010; Owens, 2009).

3.3 Incentive

In the absence of specific regulations in nanotechnology EH&S, it is up to nanotechnology firms to voluntarily implement nano-specific EH&S programs. EH&S programs are potentially costly, and thus there may be other incentives to such voluntary action:

- Increased interest in environmental issues and corporate social responsibility
- Potential liability if products could cause harm to the workers creating products containing nanomaterials and the consumers purchasing these products
- Investors may be more willing to support a business if the company is proactive in regards to protecting the health of their workers and the environment

4. Methodology

4.1 Target Audience

In order to pick a receptive target audience, we looked at two industry surveys conducted by past Bren Group Projects. In 2007, the International Council on Nanotechnology (ICON) and Environmental Defense (ED) sponsored a Bren Group Project to survey industry in order to uncover current practices regarding nanotechnology environmental health and safety (Gerritzen, Huang, Killpack, Mircheva, & Conti, 2006). The survey revealed that most firms are not engaging in nano-specific safety practices. Reasons included a lack of information and insufficient regulatory guidance (Gerritzen, et al., 2006). A follow-up survey conducted by a Bren Group Project in 2009-2010 indicates a continued disconnect (Baumgartner, Carr, Fish, & Meyerhofer, 2010). Although most companies have a general EH&S program, as required by OSHA, the majority of industry still do not have nano-specific EH&S. However, findings revealed that small, young nanotechnology companies are statistically more likely to engage in nano-specific EH&S practices than larger, established firms (Baumgartner, et al., 2010). Additionally, small companies reported lack of information as a continued barrier to implementing nano-specific EH&S. To clarify, small was classified as 1-19 employees and young was classified as being in business for 0-9 years (Baumgartner, et al., 2010). Conclusions from the previous two Bren surveys as well as our current knowledge of the growing nanotechnology industry helped us identify our target audience as small nano-startups.

4.2 Recommendations and Background Information

Twenty-seven guidance documents were compiled, with a focus on North America and Europe, and were assessed. The guidance documents included 14 from academic institutions, 11 from various government agencies in the US and the European Union (EU), one from nanotechnology companies and one from a nonprofit. We then selected the most comprehensive of all the 27 guidance documents, *Ellenbecker & Tsai 2011*, as

the baseline document for comparing all other documents (Ellenbecker & Tsai, 2011). We synthesized all the specific recommendations in the baseline document into the first column of a Microsoft Excel spreadsheet and listed all 27 documents on the top row of the same spreadsheet, right after the column of recommendations from the baseline document. We then compared all the specific recommendations from the baseline documents with specific recommendations from all other documents one after the other: Whenever a document makes the same recommendation as that in the first column (from the baseline document), we check the cell that intersects between that specific recommendation and the document. Also, whenever we found a recommendation in the other documents that was not mentioned by the baseline document, we also extracted such recommendations and add them to the appropriate section on the list of recommendations from the baseline document. The comprehensive matrix, which had 945 rows and 34 columns, obtained at the end of this comparison was translated into the recommendations contained in Abbreviated and Full CERNS. The background information section of long CERNS was synthesized from various academic journals, websites of government agencies (especially the US EPA) and the 27 guidance documents synthesized.

4.3 Economic Implication

We made a comprehensive list of the equipment and materials that were listed in both the Abbreviated and Full CERNS. We then obtained the current pricing of related items from specific suppliers, mainly via their websites (when listed) or by acquiring a quote (when not available online). Information regarding the calculation of capital projects (e.g., HVAC systems) was provided for further reference, since quotes cannot be given without an assessment of the building. The equipment and materials were then categorized by the various control measures contained in a traditional hierarchy of control for protecting workers. The traditional industrial hygiene hierarchy of exposure controls emphasizes reducing the hazard as close to the source as possible using the following controls: 1) Elimination; 2) Substitution; 3) Isolation; 4) Engineering Controls; 5) Administrative Controls; 6) Personal Protective Equipment (PPE) (Burgess, Ellenbecker, & Treitman, 2004).

5. Results

Data were compiled using the information matrix developed from the 27 different guidance documents. A total of 903 distinct recommendations were examined.

5.1 Hierarchy of Control

One-third of the guidance documents recommended personal protective equipment (PPE) as an important measure for reducing nanomaterial exposure and thereby the most frequency cited control preference. Engineering controls at 29.6% and administrative controls at 25.9% are the next most frequency cited control preferences.

Recommendations for elimination and substitution are the least frequently cited control methods at 14.8% and 18.5%, respectively (Fig. 2).

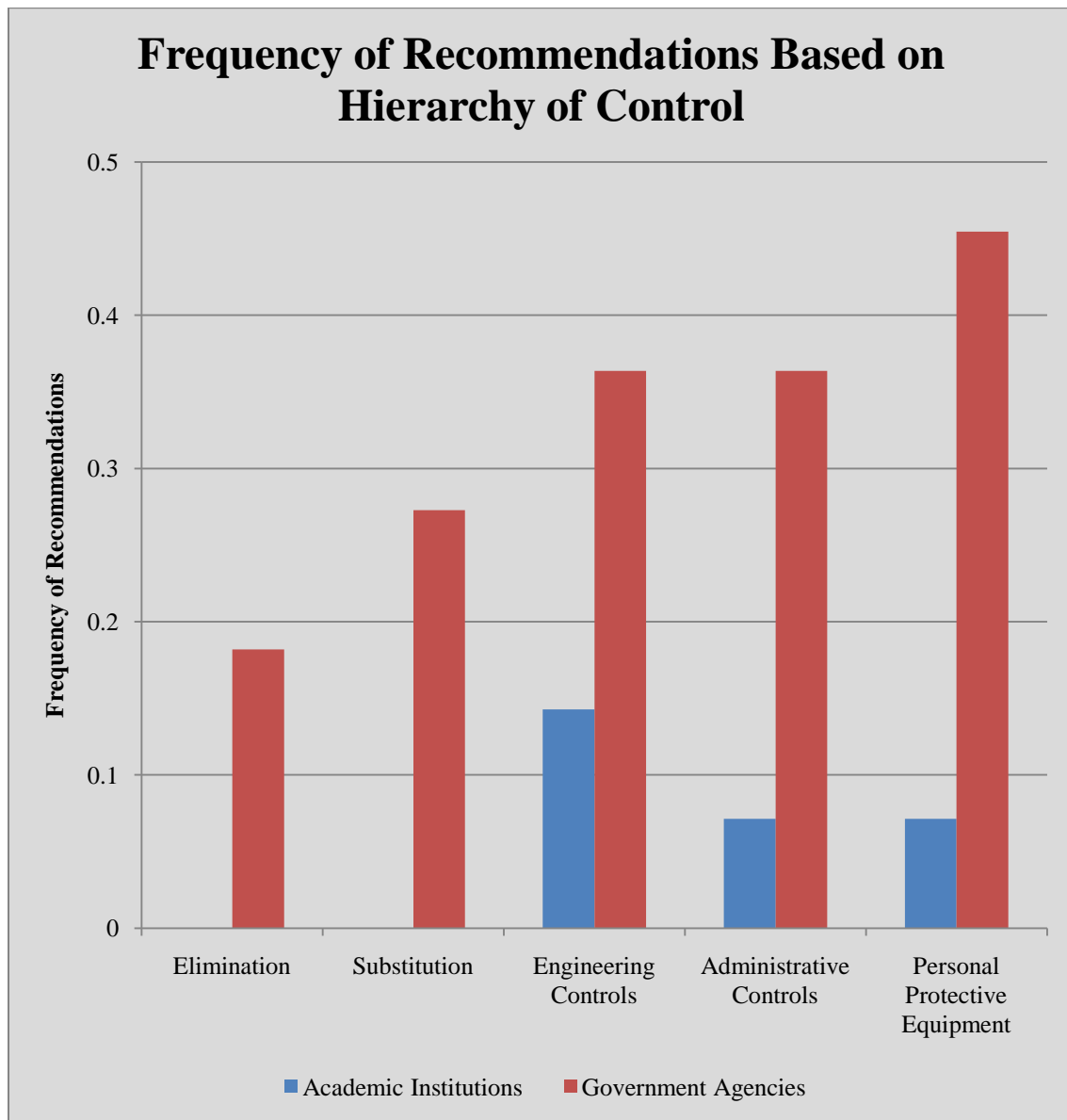


Figure 2. Frequency of recommendations recommending different types of control preferences based on hierarchy of controls

The frequency of recommendation varied somewhat across academic and government sources of guidance documents (Fig. 2). Industry and non-profit guidance documents were not included in the frequency graph (Fig. 2) because only one such document was reviewed for each category.

5.2 Consistency Across Guidance Documents

When we compared recommendations across guidance documents, we in part were evaluating the consistency of recommendations. We found that 64.2% of all specific recommendations were contained in only between 1 to 10% of all documents (Fig. 3). This means that most recommendations were “rare” and not repeated in most of the documents. Similarly, only 2.3% of reviewed recommendations occurred in 40% of the documents (Fig. 3). Again, this suggests that there was little consistency across documents.

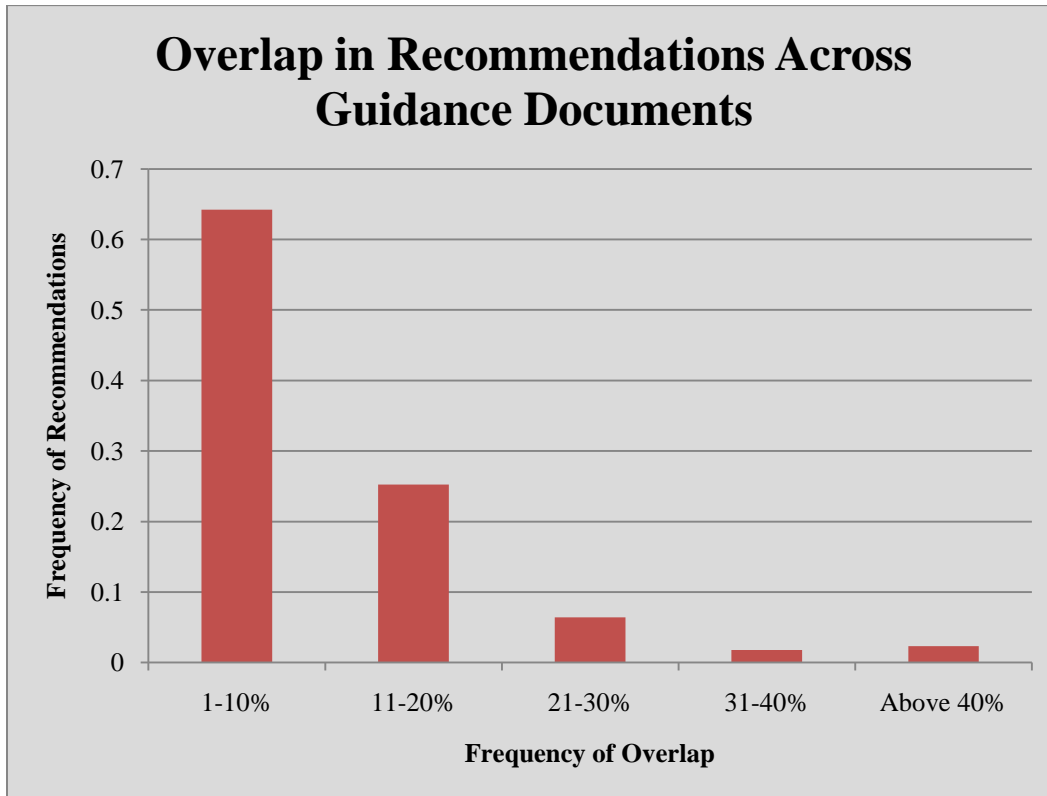


Figure 3: Overlap of recommendations across all guidance documents

When evaluated across all of the various guidance document source groups, the same pattern emerged (Fig. 4). The 0% coincidence frequency class represents the instances when one of the 903 compiled recommendations is not specifically mentioned in any guidance document from either academic institutions or government agencies. Of the compiled recommendations, 65.4% were not specifically mentioned in any guidance from academic institutions, followed by 26.3% for government agencies.

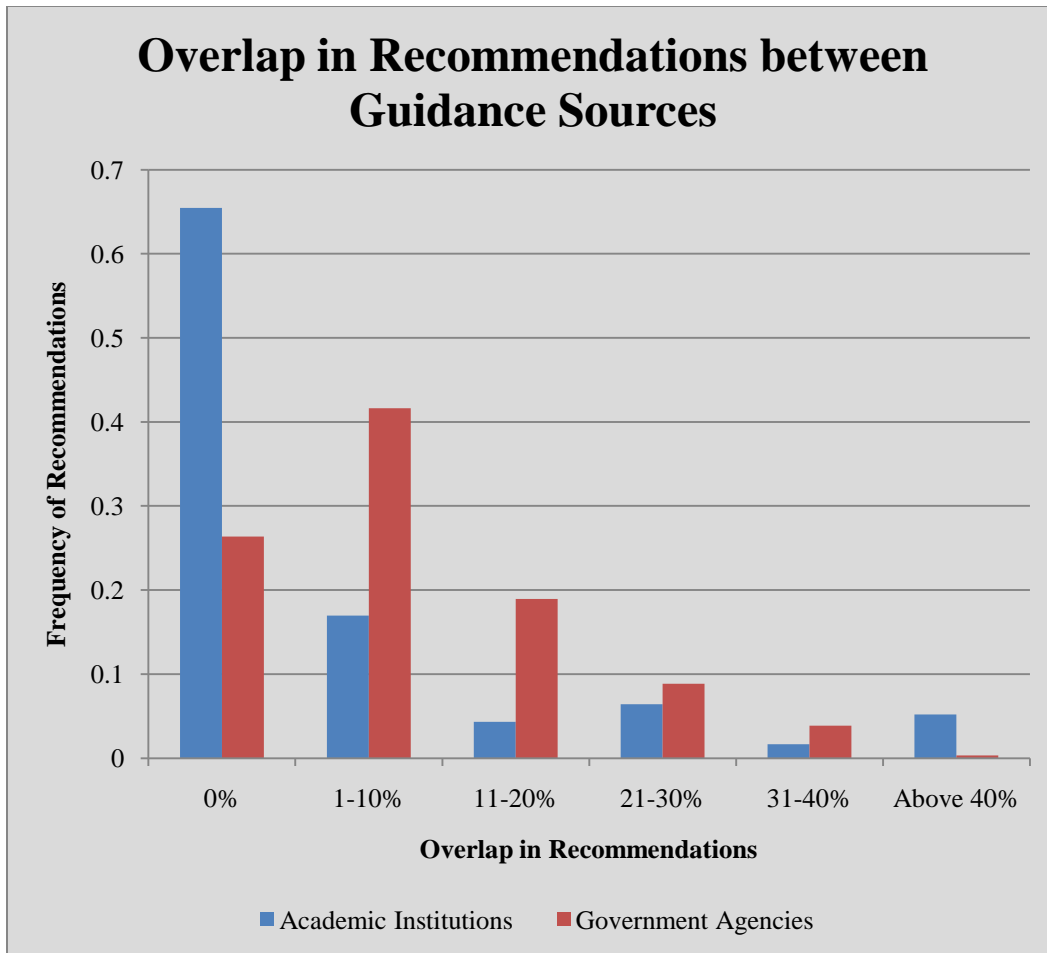


Figure 4. Overlap of recommendations, broken down by source: academic institutions and government agencies

5.3 Most Frequently Recommended Practices

Few recommendations were widely suggested across the range of available guidance (Fig. 3 and 4). When there is a convergence of recommendations in the guidance, they focus primarily on exposure control practices. The recommendations can range from engineering and administrative controls and PPE, although frequently the top recommendations are on PPE. The top 10 specific recommendations within four major sections found in the guidance documents are: control of airborne exposures (Fig. 5), control of dermal exposures (Fig. 6), fire and explosion control (Fig. 7), and spill management (Fig. 8).

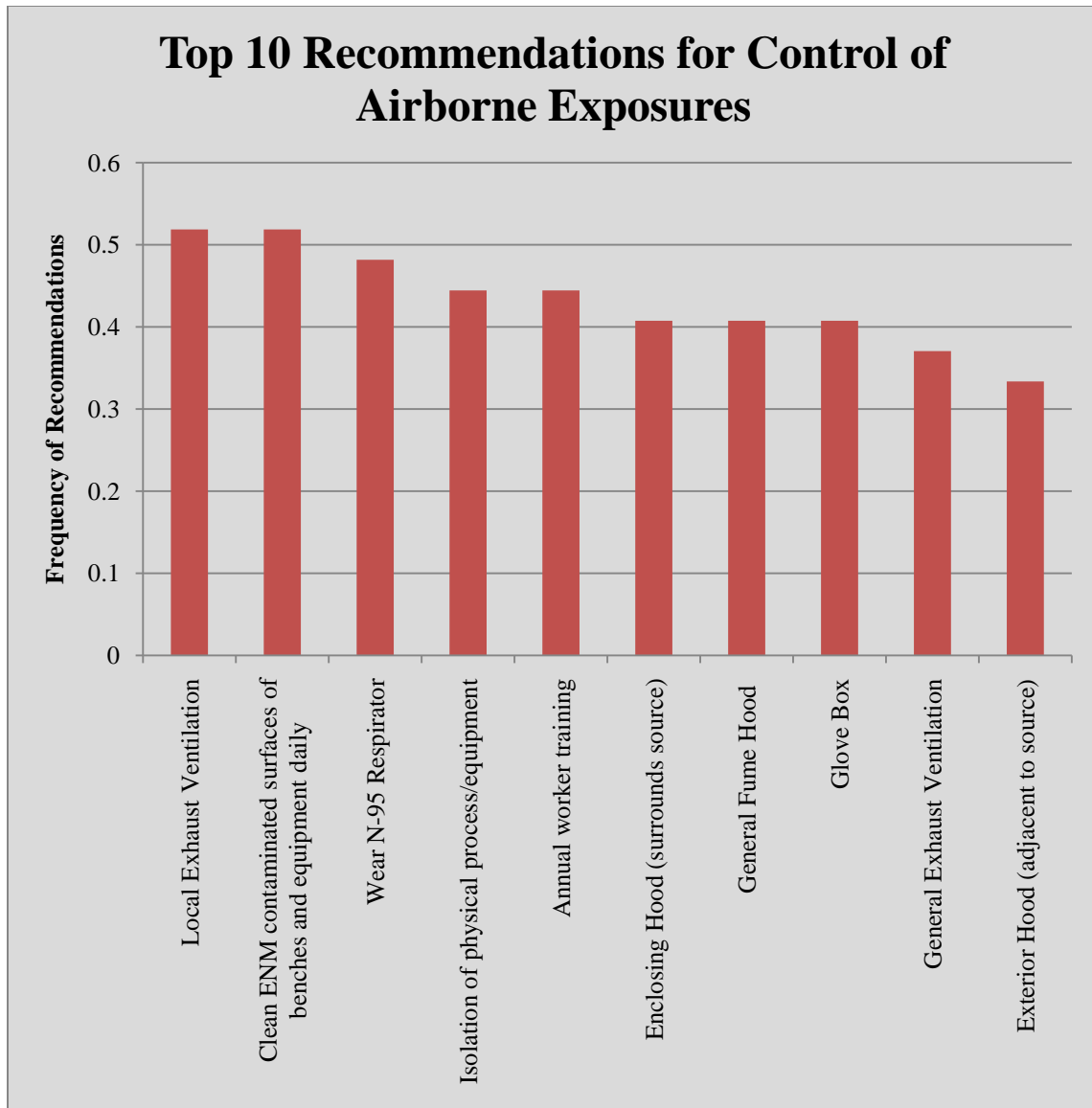


Figure 5. Top ten most frequently cited recommendations for control of airborne exposures

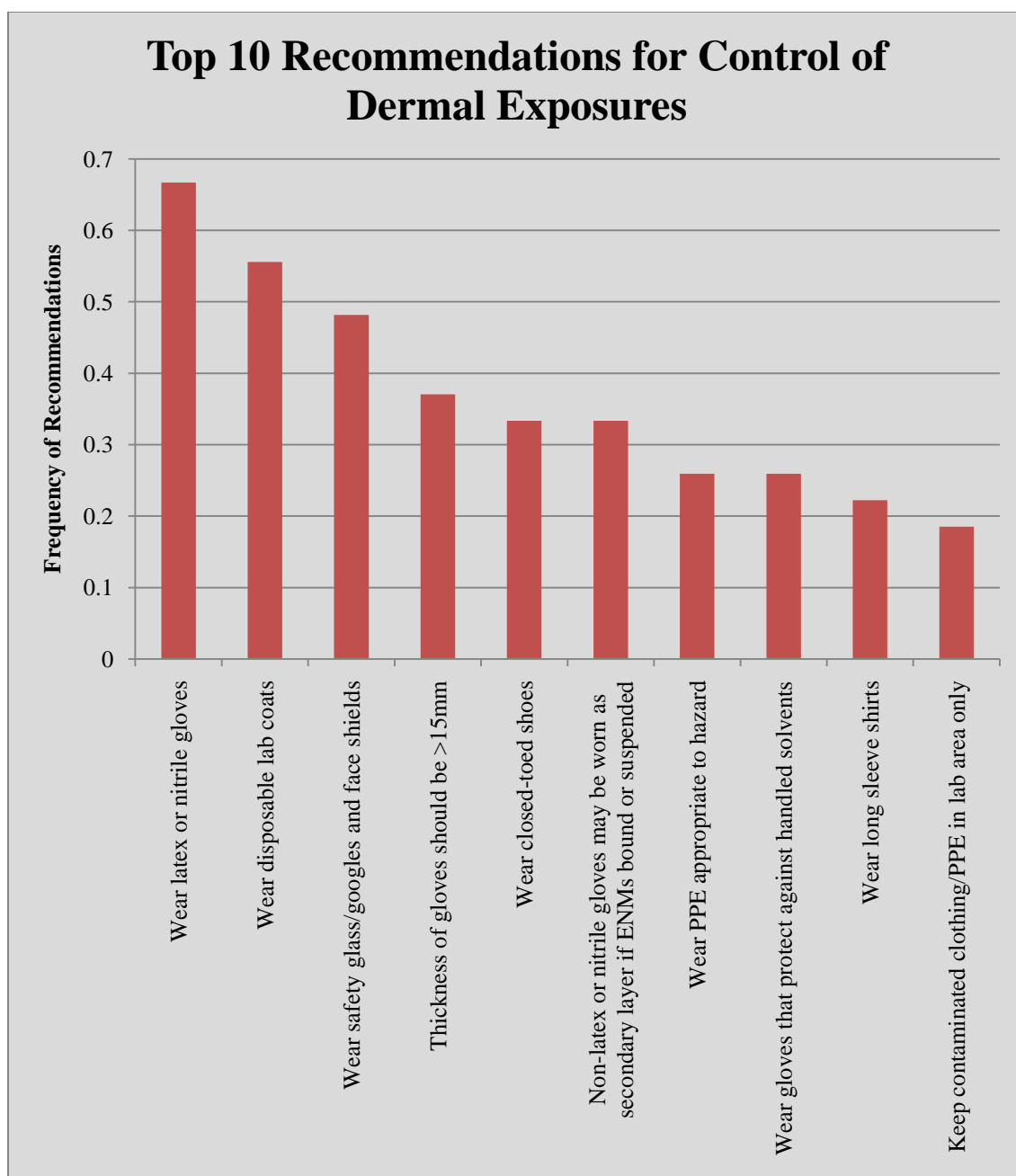


Figure 6. Top ten most frequently cited recommendations for control of dermal exposures

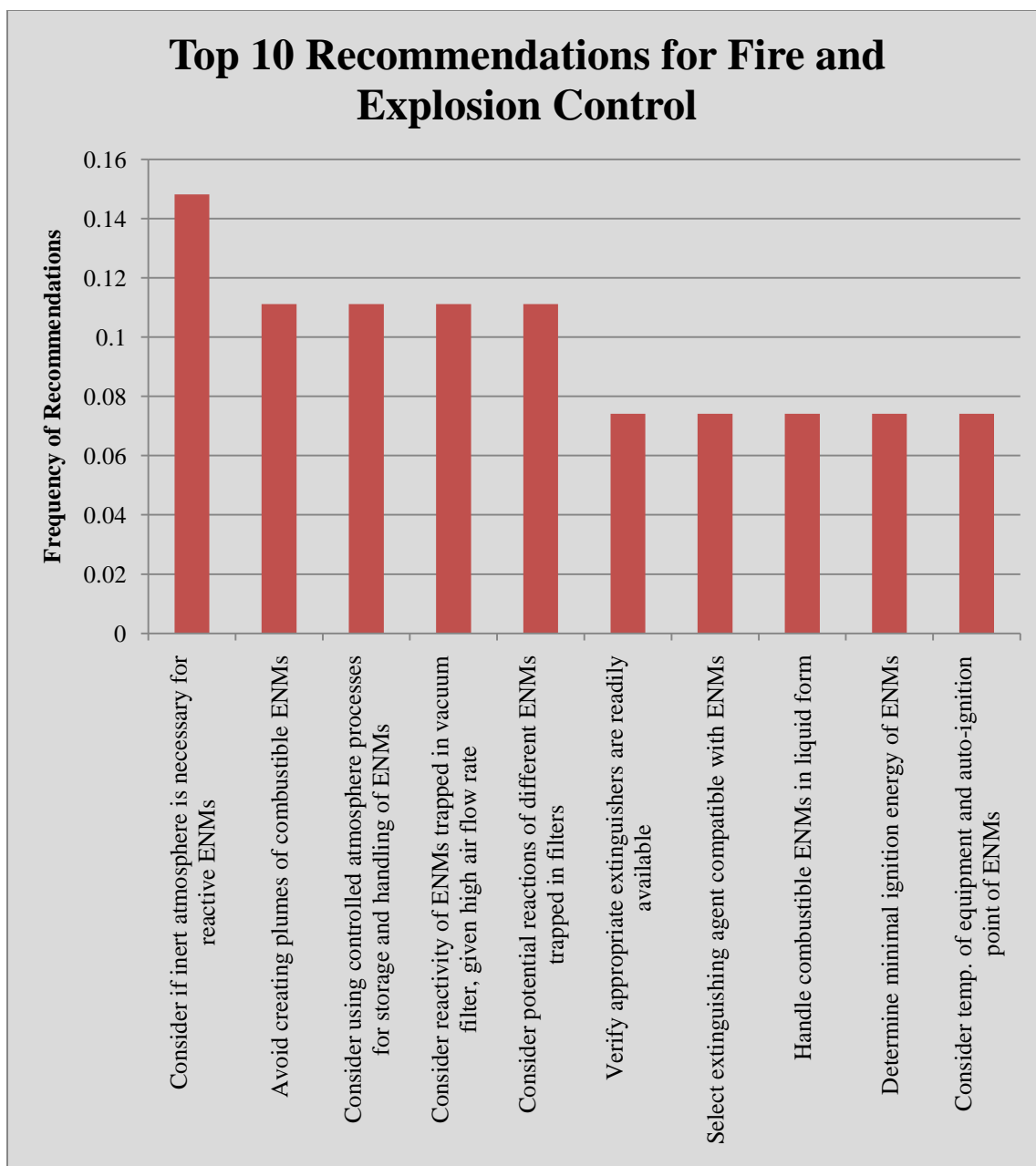


Figure 7. Top ten most frequently cited recommendations for fire and explosion control

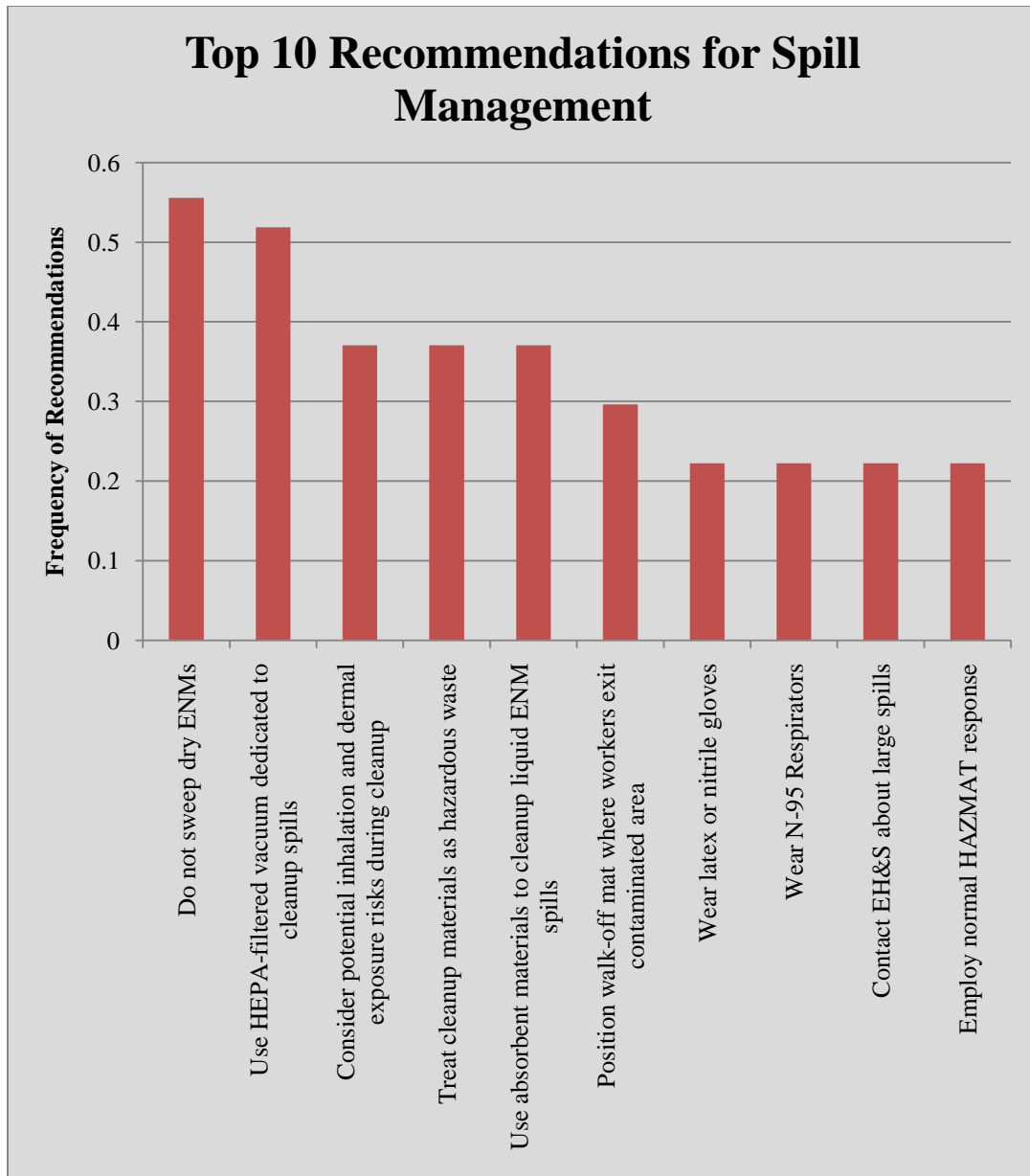


Figure 8. Top ten most frequently cited recommendations for spill management

6. Discussion

Less than 19% of guidance documents address substitution or elimination, which are considered the most effective forms of exposure control (British Standards Institution, 2007b). The novel properties of nanomaterials poses significant new risks to human and environmental health, but those novel traits are exactly what the nanotechnology industry attempts to exploit. While substitution and elimination may be appropriate for other types of materials, such recommendations are not realistic for the nanotechnology industry.

The remaining controls in the hierarchy method include engineering controls, administrative controls, and PPE. Although EH&S experts consider PPE to be the least effective and riskiest form of exposure control, PPE receives more recommendations than any of the other four tiers of the exposure control hierarchy (Fig. 2). There seems to be a disconnect between what guidance and scientific literature deem to be the most effective control procedures and what the guidance documents recommend to industry. Such a disparity in the available best guidance may lead industry to focus on PPE implementation above other control methods, thinking that extensive PPE is adequate protection.

The level of coincidence in recommendations between the various guidance documents is in general quite low (Fig. 3 and 4). Many of the reviewed guidance have different levels of specificities and focus in their recommendations of best practices, with several of guidance documents issued by academic institutions only a few pages in total length. Therefore low levels of coincidence do not indicate the relative importance of that particular recommendation. Several of the more thorough and specific documents, such as those produced by Ellenbecker and Tsai 2011, the British Standards Institute, and IRSST often go into great detail with their recommendations sections (British Standards Institution, 2007b; Ellenbecker & Tsai, 2011; Ostiguy, et al., 2010). Therefore many of their recommendations cannot be addressed in certain short documents like those issued by many academic institutions because of vast differences in scale and scope for each guidance document.

The relatively low level of coincidence also highlights the value of compiling and assessing such a wide variety of documents, because reading only one or two pieces of guidance does not provide a complete overview of the current best practices for managing exposure risks. More recommendations does not necessary translate into better management of risk, however it is important for those handling raw nanomaterials to have a more complete perspective of the best available information on the matter.

There is in no way a consensus for determining best practices in nanomaterials EH&S. For example, the top recommended practice for fire and explosion control of “considering if inert atmosphere is necessary for reactive ENMs” was only cited in 14.8% of all guidance. Specific recommendations addressed in a majority (>50%) of guidance

documents often are already common lab practices, such as wearing nitrile or latex gloves, and donning lab coats.

There is however an inherent error resulting from human judgment when determining the coincidence of recommendations across different sources of guidance. Each recommendation is assessed on whether or not it significantly differs from other recommendations. Therefore coincidence frequencies of particular recommendations possess an unknown level of error from the subjectivity involved in developing the raw dataset.

6.1 Existing Guidance

If companies want to respond to proposed incentives/drivers proactively by implementing nano-specific EH&S programs, one of their primary sources of information is nano-specific guidance documents and literature. While there are many documents, there is not yet a perfect solution for information. Available documentation ranges from general documentation published by universities and government agencies, such as NIOSH and the Department of Energy (DOE), to documents that are specific but only in one or a few areas of nano-specific EH&S, such as British Standards Institute and Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail (IRSST). The shortcomings of existing guidance documents based on the 27 guidance documents that we reviewed are illustrated in Figure 9.

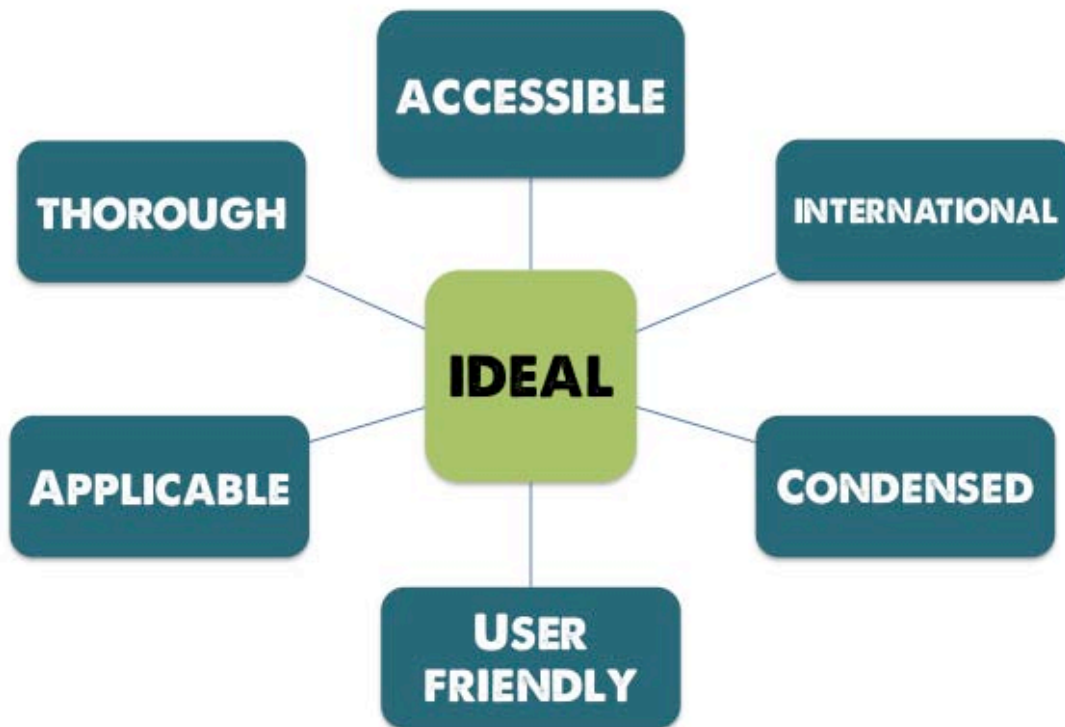


Figure 9. Qualities of an ideal, universal, nano-specific guidance document

7. Conclusions

With so many NMs EH&S guidance documents available, it is important to find out which EH&S practices are most suitable for any manufacturing or handling processes. Although CERNS synthesizes much of the available guidance practices, it is important to acknowledge the tremendous variation between firms (manufacturing processes, end-use application, etc.). Each firm should explore ways to tailor their individual EH&S programs to their firm's activities to minimize environmental impacts and ensure occupational health. There exist several institutions devoted to industrial hygiene such as the Center for Disease Control & Prevention's NIOSH that have partnered with proactive nanotechnology firms to establish individually suited EH&S practices.

It is equally important to emphasize that each company must be attentive to technological advancements that will improve monitoring, PPE, capture/disposal and other relevant areas central to EH&S practices. Furthermore, advancements in toxicology studies will increase understanding of their environmental and human health impacts throughout NMs' life cycles and may provide a suitable basis for evaluating and improving EH&S practices. In addition to this, there are also several recent regulatory developments that may mandate specific EH&S practices.

The CERNS guide is intended to consolidate existing guidance practices. Although evaluating existing guidance practices is a crucial first step towards implementing sound EH&S practices, there are many ongoing developments that could necessitate the alteration of any firms EH&S practices in the future.

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9. Appendix I: Full CERNS



CERNS: A Condensed EH&S Reference for Nanotechnology Startups

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Guidance Documents

Documents from Academia

- [In Press] Center for High-Rate Nanomanufacturing: Interim Best Practices for Working with Nanoparticles [1]
- Duke: Working Safely with Nanomaterials in the Laboratory [2]
- Harvard University: Working Safely with Nanomaterials [3]
- Journal of Occupational and Environmental Hygiene: Nanoparticle Usage and Protection Measures in the Manufacturing Industry - A Representative Survey [4]
- Lawrence Berkeley National Laboratory: Control Procedures for Engineered Nanomaterials [5]
- Massachusetts Institute of Technology: EHS Nanomaterials [6]
- Stanford University: General Principles and Practices for Working Safely with Engineered Nanomaterials [7]
- University of California Lab Safety Work Group: Nanotechnology: Guidelines for Safe Research Practices [8]
- University of California, Irvine: Standard Operating Procedure for Working with Carbon Nanotubes (CNT) [9]
- University of California, Los Angeles: Safe Handling of Dry Carbon Nanotube Powder [10]
- University of California, Santa Barbara: Engineered Nanomaterials: Guidelines for Safe Research Practices [11]
- University of New Hampshire: Nanomaterials Safety Program [12]
- University of North Carolina: Summary of Recommended Nanomaterial Risk Levels [13]
- University of Washington: Guidelines for Safety During Nanoparticle Research [14]

Documents from Industry

- DuPont: Nano Risk Framework [15]

Documents from Government

- British Standards Institute: Guidance on the Labeling of Manufactured Nanoparticles and Products Containing Manufactured Nanoparticles [16]
- British Standards Institute: Nanotechnologies - Part 2: Guide to Safe Handling and Disposal of Manufactured Nanomaterials [17]
- Commission of the European Communities: Regulatory Aspects of Nanomaterials [18]
- Department of Energy Notice: The Safe Handling of Unbound Engineered Nanoparticles [19]
- Department of Energy: Approach to Nanomaterial ES&H [20]

- Department of Energy: Secretarial Policy Statement on Nanoscale Safety [21]
- European Risk Observatory Literature Review: Workplace Exposure to Nanoparticles [22]
- National Institute of Occupational Safety & Health: Current Intelligence Bulletin 60 - Interim Guidance for Medical Screening and Hazard Surveillance for Workers Potentially Exposed to Engineered Nanoparticles [23]
- National Institute of Occupational Safety and Health: Managing the Health and Safety Concerns Associated with Engineered Nanomaterials [24]
- Scientific Committee on Emerging and Newly Identified Health Risks: The Appropriateness of Existing Methodologies to Assess the Potential Risk Associated with Engineered and Adventitious Products of Nanotechnologies [25]
- Stanford Linear Accelerator Center: Nanomaterial Safety Plan [26]

Documents from Non-Profit Organizations

- Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail: Engineered Nanoparticles - Current Knowledge about OHS Risks and Prevention Measures [27]

List of Acronyms

AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute
BSC	Biosafety Cabinet
BSI	British Standards Institute
CAA	Clean Air Act
CERNS	A Condensed EH&S Reference for Nanotechnology Startups
CNMS	Center for Nanophase Materials Sciences
CNT	Carbon Nano Tube
CPC	Condensation Particle Counter
CWA	Clean Water Act
DOE	Department of Energy
EH&S	Environmental Health and Safety
ENM	Engineered Nanomaterial
ENP	Engineered Nanoparticle
EU	European Union
FHSA	Federal Hazardous Substances Act
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GEV	General Exhaust Ventilation
HEPA	High-Efficiency Particulate-Absorbing
HVAC	Heating, Ventilating, and Air-Conditioning
IRSST	Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail
ISO	International Organization for Standardization
LBNL	Lawrence Berkeley National Laboratory
LEV	Local Exhaust Ventilation
MSDS	Material Safety Data Sheet
NEAT	Nanoparticle Emission Assessment Technique
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NM	Nanomaterial
OHS	Occupational Health and Safety
OPC	Optical Particle Counter
OSHA	Occupational Safety and Health Administration
PBZ	Personal Breathing Zone
PCMNP	Products Containing Manufactured Nanoparticles
PPE	Personal Protective Equipment
RCRA	Resource Conservation and Recovery Act
REACH	Registration, Evaluation, Authorisation, and Restriction of Chemical Substances
SEM	Scanning Electron Microscopy
SLAC	Stanford Linear Accelerator Center
TEM	Transmission Electron Microscopy

TiO ₂	Titanium Dioxide
TSCA	Toxic Substances Control Act
TURI	Toxics Use Reduction Institute
UC CEIN	University of California Center for Environmental Implications of Nanotechnology
ULPA	Ultra Low Particulate Air
US FDA	United States Food and Drug Administration
US EPA	United States Environmental Protection Agency
UV	Ultraviolet

1. Foreword

When designing an environmental, health and safety (EH&S) program, it is especially important to highlight diversity within the nanotechnology industry. Different types of nanomaterials characterized by a wide array of special properties are developed and/or utilized by different companies. The intention of this guide is to provide a useful synthesis of nanotechnology specific EH&S practices. Contextual knowledge is provided, detailing relevant information about nanomaterial properties, and a brief description of EH&S risks and regulatory developments. This guide is primarily intended for companies seeking to determine adequate practices and EH&S standards while handling nanomaterials. It should be noted that while this guide provides initial guidance about nanomaterial EH&S, it should not be the sole basis for the implementation of programs to address any individual company's EH&S concerns. It may be necessary to develop a specially devised set of EH&S practices with the aid of a professional, such as an industrial hygienist, due to the differences in usage, manufacturing processes, storage environmental and distribution. Further information about specific EH&S practices described in this guide can be found in the reference documents cited.

2. Why You Need This Document

As with the advent of most technologies, there is a dearth of information about nanotechnology including the physicochemical properties of nanomaterials as well as their potential impacts on human health and the environment. The pace of growth is exceeding our preparedness for any adverse effects.

2.1 Ecotoxicology and Human Health Risks

An exposure route is the path by which nanomaterials enter various receptors [28]. Environmental exposure routes can be through wastewater, fugitive emissions, product degradation and solid waste disposal. Likewise, human exposure routes in the workplace, on the focus of this research, include through respiration and dermal contact, and possibly ingestion. Maynard *et al.* published a report in 2006 that supported the need for further assessment of the risks associated with products containing nanomaterials [29]. The following examples reveal some nanomaterial exposure routes that have had negative outcomes.

In 2008, Poland *et al.* published results from a scientific study, which revealed that carbon nanotubes (CNTs) cause asbestos-like effects when injected into mice, leading to

mesothelioma [30]. In 2009, Song *et al.* published a report of toxic effects of seven female workers who handled nanomaterials, two of which died [31]. During hospitalization, it was revealed that prolonged and unprotected exposure to nanomaterials was likely to blame [31]. These two reports are extreme examples of evidence for possible harm from human exposure to nanomaterials.

Additionally, nanomaterials in consumer products are possibly finding their way into the environment, posing vulnerabilities for terrestrial and marine organisms [32]. For example, in 2010, Goyal *et al.* published results of a scientific study regarding the effects of single walled carbon nanotubes (SWCNTs) on the bacterial communities in activated sludge, showing that community changes occur [33]. These examples are just a few of the many potential negative effects of exposure to nanomaterials.

2.2 Current and Potential Regulations in the US

In order to understand the development of nanotechnology EH&S practices, it is necessary to understand how nanomaterials are currently regulated in the US, and what may happen in the future. The following federal agencies have a responsibility when it comes to nanotechnology:

- United States Environmental Protection Agency (US EPA)
- United States Food and Drug Administration (US FDA)
- Occupational Safety and Health Administration (OSHA)
- National Institute for Occupational Safety and Health (NIOSH)

The US EPA, US FDA, and OSHA have regulatory authority. OSHA has responsibility to ensure a safe workplace by enforcing standards, and they currently require EH&S but not nano-specific EH&S. NIOSH is not a regulatory body but is responsible for conducting research and making recommendations for the prevention of work-related injury and illness. NIOSH has written a guidance document with nano-specific EH&S recommendations. Because there are currently no nano-specific regulations in the United States, in order to accomplish these missions the US EPA, US FDA, and OSHA must use other legal mechanisms embedded in existing environmental statutes.

2.2.1 Current Regulations

2.2.1.1 Toxic Substances Control Act (TSCA)

TSCA regulates new and existing chemicals on the market. While there is no reference to nanomaterials (NMs) in TSCA, the US EPA has used TSCA to regulate over 100 NMs as new chemical substances based on their differences in physical form and novel uses and applications [34]. Firms that intend to manufacture NMs for commercial use are required to submit a pre-manufacture notice (PMN) to the EPA's Office of Chemical Safety and Pollution Prevention (OCSPP) [35]. The information provided by the company in the PMN includes occupational health and safety practices, consumer product safety testing and other relevant information that the EPA will use in health and safety assessments. Approval for manufacture can then be conditionally granted after the EPA completes a risk assessment. Based on the results of this risk assessment, conditional approval may be granted to the company to manufacture their NM. Conditions may include limiting the use of the NMs, requiring the use of personal protective equipment, limiting release into the environment, proper disposal, and/or requiring further testing.

2.2.1.2 Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)

FIFRA is used to regulate the distribution and use of pesticides in the United States [36]. The EPA defines a pesticide as “any substance or mixture of substance intended for preventing, destroying, repelling, or mitigating any pest”, and as such, FIFRA regulations pertain to herbicides, nematocides, insecticides, larvicides, fungicides, rodenticides, antimicrobial compounds not regulated by the US FDA, and some swimming pool sanitization chemicals [37]. Any firm wishing to sell a pesticide must apply to register their product with the EPA. In 2008, the US EPA required registration of silver nanoparticles as pesticides under FIFRA, based on a 2007 case where a washing machine was found to cover loads of laundry with silver nanoparticles after each wash [27]. As a result of this case, FIFRA is now used to regulate, and requires registration of, any NPs that fit the EPA's definition of a pesticide.

2.2.1.3 Clean Air Act (CAA)

The Clean Air Act (CAA) gives the EPA authority to regulate fuel additives that may pose a human health risk from their emissions to air [38]. The CAA requires new fuel additives to be registered with the US EPA and, as with TSCA and FIFRA, manufacturers and producers are required to submit data necessary for risk assessments. Therefore, the CAA can be used to regulate NMs that are present in fuel additives. One NM-based fuel additive is currently on the list of registered diesel additives [39]. It is important to note

that small businesses with revenues of less than \$10 million are exempt from submitting both a literature review of known health effects and animal testing for toxicity under the CAA [38]. This is known as a small business exemption and applies to many nanotechnology startup companies.

2.2.2 Potential Regulations

2.2.2.1 Possible Nano-Specific EH&S

OSHA and NIOSH work collectively to promote a safe workplace. OSHA serves as the regulatory arm while NIOSH conducts research and makes recommendations, which support OSHA. OSHA has the authority to use NIOSH's findings to enforce standards. Despite NIOSH's release of "Approaches to Safe Nanotechnology: Managing the Health and Safety Concerns Associated with Engineered Nanomaterials", in which they make nano-specific EH&S recommendations, OSHA does not currently require nanotechnology firms to have nano-specific EH&S programs [24]. In the event that more toxicology data is available and NIOSH's nano-specific regulations become standards enforced by OSHA, it is imperative that firms are proactive and prepared.

2.2.2.2 Possible TSCA Reform

The United States Environmental Protection Agency (EPA) has been regulating new nanoscale materials as novel chemical substances by utilizing authorities granted under TSCA [40]. Despite there being no reference to NMs in TSCA, the EPA has been able to classify NMs as new chemical substances based on their differences in physical form and their new uses and applications [40]. On July 22, 2010, the TSCA Reform Bill (H.R. 5820) was introduced to the House of Representatives in an effort to revamp TSCA [41]. TSCA reform would require manufacturers and producers of chemicals to disclose more data, and would also make it easier for the EPA to ban chemicals that cause unreasonable risk [36, 41].

2.3 Incentive

In the absence of specific regulations in nanotechnology EH&S, it is up to your company to voluntarily implement nano-specific EH&S programs. EH&S programs are potentially costly, and thus there may be other incentives to such voluntary action:

- Increased interest in environmental issues and corporate social responsibility
- Potential liability if products could cause harm to the workers creating products containing nanomaterials and the consumers purchasing these products

- Investors may be more willing to support a business if the company is proactive in regards to protecting the health of their workers and the environment

2.4 Existing Guidance

If you want to respond to these drivers proactively by implementing nano-specific EH&S programs, one of your primary sources is nano-specific guidance documents and literature. This can be challenging for firms because existing guidance ranges from general documentation published by universities and government agencies to documents that are specific but only in one or a few areas of nano-specific EH&S. Additionally, organizations are devising sets of recommendations worldwide, but they have not been cross-compared for the sake of thoroughness, credibility, common agreement, and best practices. The shortcomings of existing guidance documents based on the 27 guidance documents that we reviewed are illustrated in Figure 1. We believe our document addresses these problems and provides firms with the most comprehensive source out there.

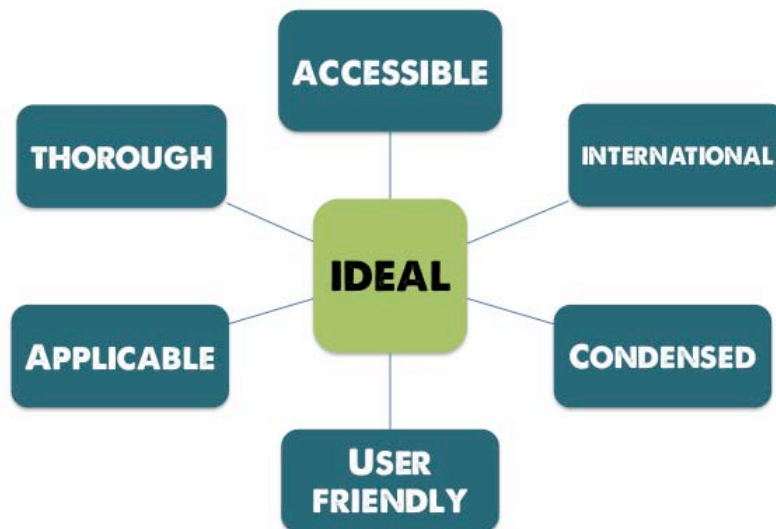


Figure 1. Qualities of an ideal, universal, nano-specific guidance document

3. Basics You Should Understand

3.1 Nanomaterial Properties

3.1.1 Size

Nano-sized usually refers to matter that has dimensions of 1-100 nanometers (nm) [34]. However, there is no complete understanding or agreement on the dimensions at which

materials exhibit novel properties that impact environmental, health and safety risks. According to ISO Standard TS 27687:2008, different terms for nanomaterials infer different nano-sizes:

Nanoplate—refers to 1 external dimension measuring 1-100 nm

Nanofiber—refers to 2 external dimensions measuring 1-100 nm

Nanoparticle—refers to 3 external dimensions measuring 1-100 nm

These terms all reference “**nano-objects**” which are all building blocks of the larger matrices commonly known as **nanomaterials** (NMs). Although nanoparticles themselves are on the nanoscale, they are highly prone to agglomeration (or clustering) at which point their size changes.

As a consequence of their size, nanoparticles have the capability of being inhaled and deposited in the respiratory tract. NMs can then enter the blood stream and tissues in humans and other organisms. Several studies, including a study by Takenaka *et al.*, reveal that particle size affects distribution pathways in the lungs because fine particles are easily engulfed and ingested by macrophages in the alveolar region of the pulmonary system [42]. Elimination of these respirable particles may take a long period of time depending on the solubility of the nanomaterial. While the size of NMs creates opportunities for drug delivery and gene therapy, small size also poses risks, as little is known about specific cellular interactions.

3.1.2 Reactivity

When materials are in a nanoscale form, there is more surface area per unit mass, referred to as a large surface area-to-volume ratio [7]. Due to the small dimensions of nanoparticles, their reactivity is different than particles of a larger size, resulting in unpredictable behavior under varying environmental conditions [43]. For instance, titanium dioxide (TiO₂) does not normally exhibit antimicrobial properties, but is harmful to microbial life in nanoscale form [44]. As a result of the large surface area-to-volume ratio, NMs will have a higher number of reactive sites on their surface [45]. Reactive sites on the surface are much more susceptible to unintended modification of effects as a result of “particle coating, surface treatments, surface excitation by ultraviolet (UV) radiation, and particle aggregation” [22]. Defective surface groups have the potential to become reactive sites that will react unintentionally with the surrounding environment [45].

Studies of the behavior of fine dust (micron-scale) particles reveal the increased risk of explosion and ignition with diminishing particle size [27]. Nanomaterials are also often

designed as catalysts (substances that increase the speed of reactions or lower the temperatures required to initiate reactions) because the high surface area to volume ratio of NMs allow for higher concentrations of reactive sites. Nanomaterials that are catalysts can stimulate exothermic (heat producing) reactions at the nanoscale that can pose a fire hazard unique to nanomaterials [24]. Carbonaceous (carbon-rich) and metal dusts are of particular concern because they can easily catch fire and explode when exposed to both air and an ignition source [46].

3.1.3 Toxicity

The framework for evaluating health risks resulting from exposure to toxic substances incorporates toxicity along with dosage levels [24]. Dose can be broadly referred to as “how much” toxic substance comes into contact with a person and “how long” those substances stay in contact [17]. Health risks from exposure are influenced by three factors: duration of exposure, how much of the toxic substance to which the individual is exposed, and toxicity of the substance. The risk of deleterious effects arising from contact with toxic substances is generally correlated with the level of dosage [27]. Mass concentrations of toxic substances are measured to evaluate the dosage [25]. In evaluating health risks from exposure to NMs, a problem lies in the fact there is little known about the toxicity of most engineered nanomaterials (ENMs) [8, 11, 24].

Particle counters measure the concentration of particles that fall within different size ranges, and can aid the evaluation of exposure risks [17, 25, 27]. However, particle counters do have disadvantages, which limit their effectiveness at evaluating exposure potentials. First, particle counters cannot distinguish particulate types; therefore naturally occurring nanoparticles and NMs composed of completely different materials may be counted together [24]. Also, the concentration of nanoparticles can decrease over time if agglomeration occurs, resulting in temporal variations in particle count measurements [25]. Both mass concentration and particle count measurements provide useful information, but both have limitations.

3.2 Nanoscale Safety Goals

It is recommended that nanomaterial safety protocols be continually reviewed and updated [22]. As toxicology studies are published, the knowledge of the effects of specific nanomaterials will grow, thus increasing the potential that current best management practices will change [22]. An effective way to ensure that these actions are carried out in an efficient and timely manner is to designate a professional who will oversee the review of new science, incorporation of science into safety protocols, and

the communication of new procedures to affected employees [15]. When new information is available that affects the manufacturing of specific nanomaterials, a review of current handling practices must occur [15]. A decision will have to be made as to how this review will effect production and how to modify current practices to incorporate new information [15]. If changes are made to current operating procedures, all affected personnel must be notified as soon as possible to expediently enact new or altered procedures [15].

4. Recommendations

The following recommendations have been extracted from guidance documents of varying sectors: academic, government, industry, and non-profit. The goal was to assess how recommendations compared across the sectors and what was most commonly recommended. We have taken the recommendations directly from guidance documents, with the full name of the guidance document the information was sourced from for you to reference for further information. We have also provided a list of documents that support the recommendations listed in numbers directly following each recommendation. The list of documents with their respective number is listed at the beginning of this document.

If you would like to read the recommendations directly from the documents themselves, we have done the legwork for you. At the end of each section, there is a list of documents with specific page numbers that address each topic. These documents address the topic very clearly and provide adequate information in order to help you make the best decision for your company. Remember, these are neither exhaustive nor absolute lists. There are many guidance documents available to the nano-industry.

4.1 Hierarchy of Nanomaterial Hazardous Control

Nanomaterials have greater potential for exposure and EH&S risks than the same chemical substances composed of larger particles and structures. Therefore, NMs may require a different set of hazard and exposure controls than the controls utilized when handling larger particles and structures of the same substance. In addition to the physical form, several factors influence the selection of exposure controls for NMs, including quantity of NMs handled and task duration [47]. As each of these variables increase, exposure risk becomes greater as does the need for more efficient exposure control measures (Figure 2 and 3) [24]. For instance, operations involving easily dispersed dry NMs deserve more attention and more stringent controls than those where the NMs are embedded in a solid or suspended in a liquid matrix [1]. Furthermore, NMs in a gas phase pose the greatest risk for inhalation [27]. Liquid nanoparticle suspensions typically offer little opportunity for inhalation exposure during routine operations, but may represent a significant hazard when spilled [1].

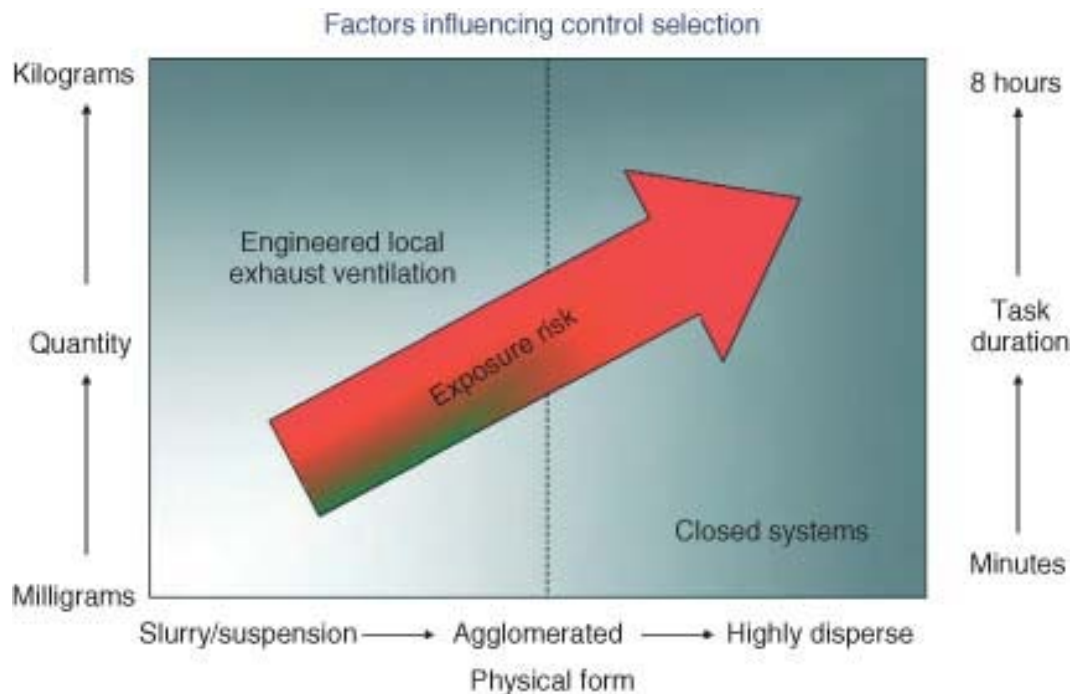


Figure 2: Factors Influencing Control Selection Source: NIOSH Approaches to Safe Nanotechnology [24]

The traditional industrial hygiene hierarchy of exposure controls emphasizes reducing the hazard as close to the source as possible using the following controls:

- Elimination
- Substitution
- Isolation
- Engineering Controls
- Administrative or Work Practice Controls
- Personal Protective Equipment (PPE)

Firms manufacturing and handling NMs could employ this standard hierarchy of hazard controls to reduce hazardous exposures [48].

4.1.1 Elimination Control

The primary example of source control is elimination of the hazard [49]. This approach may be difficult to implement with NMs, which exhibit unique, commercially viable properties that could also cause potential hazards. One approach to reducing the potential toxicity of a given nanoparticle may be to coat the particle with a less hazardous material that still allows the commercial properties to be exhibited. However, the durability of such coatings after the particles enter the environment or the body would need to be evaluated thoroughly [49]. Other examples of elimination control include the use of minimal amounts of nanomaterials, the proper disposal of redundant equipment that contain nanomaterials, the removal of excess quantities of nanomaterials accumulated over time (e.g., in absorbent mats, reactor, biosafety cabinets or other surfaces), and proper waste disposal and spill management [49].

4.1.2 Substitution Control

Substitution refers to replacing high-risk nanomaterials with low or no risk nanomaterials or changing the physical state of the nanomaterial being handled (e.g., using solution instead of powders) [49]. Substitution control could also be changing a process that has a high probability of worker and environmental exposure to a more enclosed process. As an example, nanomaterials in powder form pose greater risk than the same nanomaterial in solution; therefore, processes involving nano-powders can be substituted with less risky nano-solutions or pellets [49]. The US Department of Energy recommends the following order of preference when handling nanomaterials (1 being lowest risk and 4 being highest risk):

1. Solid materials with embedded 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 aggregates

Another option would be to substitute engineered nanoparticles may be replaced with naturally occurring nanoparticles. For instance, Xia *et al.* (2010) compared isolated organic nanoparticles from English Ivy (*Hedera helix*) with titanium dioxide (TiO₂) nanoparticles contained in some sunscreens [50]. The ivy nanoparticles were more efficient in blocking UV light, less toxic to mammalian cells, easily biodegradable, and had a limited potential to penetrate human skin. These results indicate that the organic nanomaterial provides a safer alternative for both workers and consumers than the metal nanoparticles currently used by sunscreen makers. The effectiveness of substitution control is dependent on the choice of replacement.

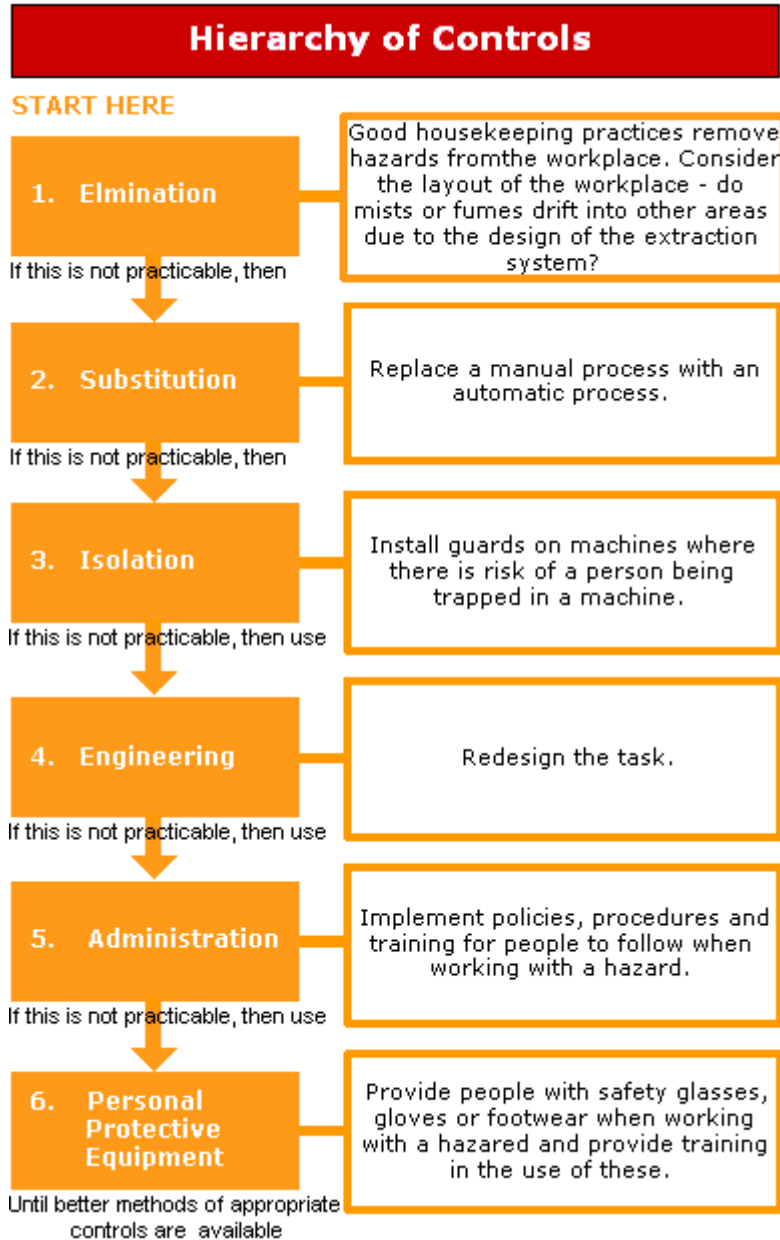


Figure 3: Hierarchy of Controls Source: SafeWorks SA
<http://www.safework.sa.gov.au/contentPages/images/HierarchyControls2.gif>

4.1.3 Isolation Control

Isolation control involves confining the production or manipulation of nanomaterials to a place (work stations) that only trained workers may access [11]. Nanomaterial

workspaces and storage areas therefore should be designated and labeled as such [5, 13, 19, 20, 26]. Isolation control especially reduces the risk of exposing other workers or visitors to nanomaterials, as these groups of people are often not wearing the necessary PPE. Personnel who do not normally handle NMs, such as equipment or facilities maintenance staff, may still come into contact with nanomaterials. These types of personnel must be warned of the potential hazards of NMs and the precautions they should take to protect themselves if the equipment or facilities cannot be decontaminated before their work [13, 14]. Signs should be posted indicating hazards, personal protective equipment requirements, and administrative control requirements at entry points into designated areas where nanomaterials are handled [13, 19, 20, 26].

4.1.4 Engineering Controls

Engineering controls are practices employed to prevent worker exposure to hazardous materials and activities. Examples of engineering controls include glove boxes and bags, HEPA-filtered biosafety cabinets, and/or other negative-pressure enclosures. The most effective engineering controls are generally practices that provide a high level of control, independent of worker interactions [23]. Enclosures used to perform work with nanomaterials should operate at a negative pressure differential^a compared to the worker's breathing zone [51]. There may be limits to the kind of processes that can be carried out in engineering enclosures. If a process cannot be enclosed, then other engineered systems (e.g., snorkel hood) should be applied to control fugitive emissions of engineered nanomaterials or hazardous precursors that might be released [5, 19, 20, 26].

4.1.5 Administrative Controls

Administrative controls involve changing work procedures and increasing employee awareness through practices such as written safety policies, supervision, and scheduling hazardous jobs outside normal working hours to reduce general exposure. Generally, administrative controls contribute to reducing worker exposures but do not actually modify the work environment [1]. Education and training with the goal of reducing the duration, frequency, and severity of exposure to hazardous chemicals or situations is also an important form of administrative control. Administrative controls may also include custodial practices such as cleaning all surfaces potentially contaminated with NMs at the end of each shift using a HEPA vacuum and/or wet wiping methods. They

^a Negative pressure differential is achieved when air is evacuated from an area, room or hood. Laminar flow or biosafety hoods often use negative pressure to sweep away contaminants from a specific processor in areas where particles and/or other contaminants are being generated.

typically require significant resources to be maintained over long periods of time for continuing levels of effectiveness. They are also generally highly dependent on worker behavior.

4.1.6 Personal Protective Equipment (PPE) Controls

PPE is important in situations in which engineering controls cannot be installed due to the temporary nature of a process, or when engineering controls will not provide sufficient exposure control [47]. When employed by itself, PPE is considered the least reliable form of control, but effectively complements other types of control practices [47]. Appropriate PPE should be worn on a precautionary basis whenever the failure of a single control could entail a significant risk of exposure [1, 3, 9-12, 14]. Hazard evaluation should be conducted to determine PPE appropriate for the level of hazard [5, 9, 12, 18, 20, 22, 26, 27]. Examples of PPE include closed-toed shoes, safety glasses, goggles, gloves, NIOSH-approved N-95 respirators, long sleeve shirts, long pants, and laboratory coats.

4.2 Fire and Explosion Control

Three components are necessary for fire and explosions to occur:

- Combustible materials (e.g., dust particles, wood, metal dusts)
- Substance or gas to cause it to burn (e.g., peroxide, oxygen, air)
- Ignition source (e.g., open flame, heat)

All guidance recommendations pertaining to nanomaterial fire and explosion control address how to eliminate or reduce the components necessary for fire and explosion to occur (Figure 4) [27].

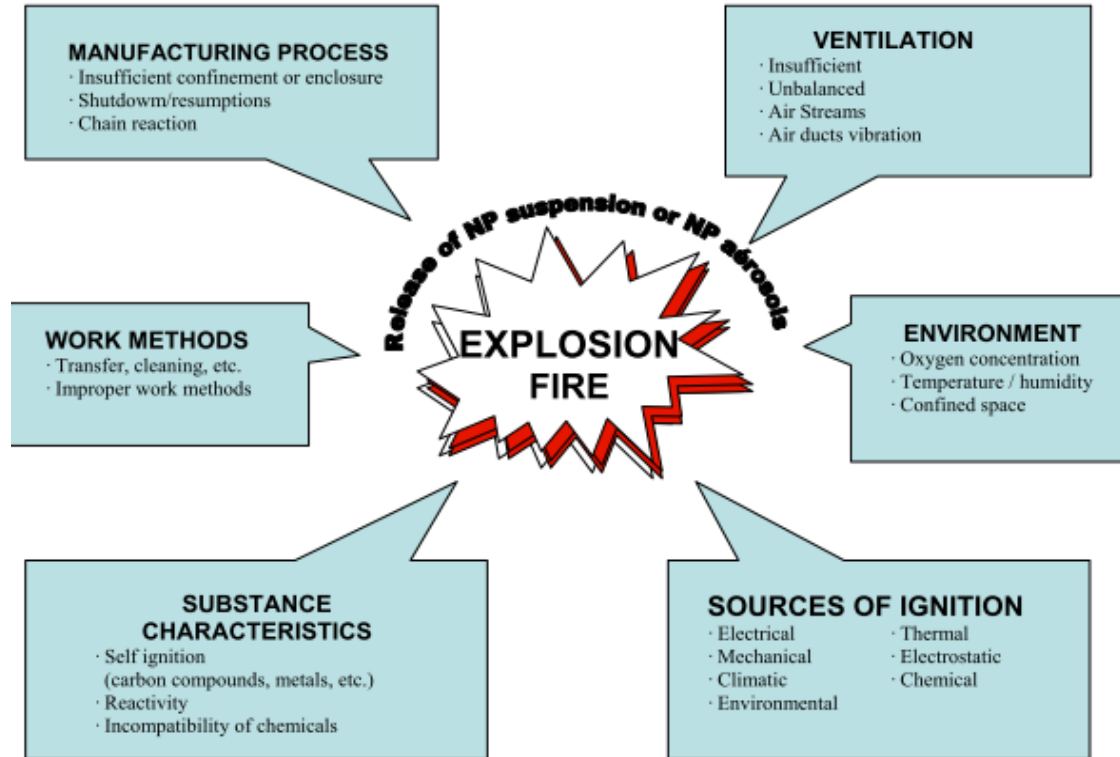


Figure 4: Conditions that increase risk of explosions or fires by engineered nanomaterials Source: IRSST’s *Engineered Nanoparticles, Current Knowledge About OHS Risks and Prevention Measures* [27]

4.2.1 Identify Fire Risk

IRSST’s *Engineered Nanoparticles, Current Knowledge About OHS Risks and Prevention Measures* specifically lists five steps in identifying fire risk potential [27]:

- “Identify and characterize the products likely to produce fires (physical state and physicochemical characteristics)” [27]
- “Know the conditions of storage and use of the substances: temperature, volume, type and tightness of the containers, ventilation, access control, separation of the products, lighting, construction materials, etc.” [27]
- “Know the environmental conditions where the nanomaterials are handled” [27]
- Quantify the amount of material stored, handled, and transported [27]
- Identify possible sources of ignition (e.g., open flames, electrical equipment, heat from reactions) [27]

4.2.2 Reduce Fire Risk and Control for Explosion

The following list is a set of general guidelines taken directly from IRSST's *Engineered Nanoparticles, Current Knowledge About OHS Risks and Prevention Measures* on how to reduce fire risks [27]:

- "Use dustproof mechanical and electrical equipment whenever possible" [27]
- "Prevent dust accumulation outside the equipment" [27]
- "Prevent dust emissions from open bins and drop points" [27]
- "Maintain the highest workplace maintenance standards" [27]
- "Eliminate the ignition sources" [27]
- "Isolate the risky operations, either by distance or by construction" [27]
- "Install explosion vents on the equipment and buildings" [27]
- "Ensure adequate fire protection" [27]
- "Store these materials in sealed containers or tanks" [27]
- "Handle the materials in closed and sealed tanks or pipe systems" [27]
- "The disposal systems must prevent formation of dust cloud" [27]
- "Train the employees in the risks of combustible dusts and the prevention measures" [27]

4.2.3 Reduce Sources of Ignition

- Wear anti-static shoes to reduce the build-up of static charge, which may ignite nanomaterials [17].
- Perform maintenance on machinery and equipment to ensure they do not generate sparks or excessive heat [27].
- Normally stable compounds captured on HEPA filters may become fire hazards when subject to the increased airflow [20].

4.2.4 Reduce Available Oxidants

- Use controlled-atmosphere production and storage processes, using carbon dioxide, nitrogen, or another inert gas to reduce the risks of fire and deflagration [17].
 - Caution: This system creates the potential hazard of asphyxiation for workers [17].

4.2.5 Contain Combustive Material

- Store nanomaterials properly [27].
- Reduce airborne emissions of materials [27].

- Understand the characteristics of the substance [27].

4.2.6 Prepare for Fire and Explosions Incidents

- Smoke and/or temperature detectors [27]
- Easily accessible exits [27]
- Readily available fire extinguishers [27]
 - Should be chosen based on the types of materials used; needs to consider the potential incompatibilities between the extinguishing (retardant) product and the material that is on fire [27].
 - Example: water and metal dusts react to form hydrogen gas, which easily combusts and can further worsen a fire situation. To extinguish a metal dust fire, IRSST suggests use of chemical powders designed to work in those situations, and to ensure firefighting efforts do not further mobilize the metal dusts to create additional fire risks [27].

4.2.7 Further Information

The following guidance documents provide a comprehensive set of recommendations for fire and explosion control:

- IRSST *Engineered Nanoparticles, Current Knowledge About OHS Risks and Prevention Measures* [27] (Pages 34-37, 79-83)
- British Standards Institute *Part 2: Guide to Safe Handling and Disposal of Manufactured Nanomaterials* [17] (Page 13)
- NIOSH *Approaches to Safe Nanotechnology* [24] (Page 21)

4.3 Workplace Monitoring (Exposure Assessment and Characterization)

Standard laboratory practice quantifies nanomaterials through mass measurements. Most guidance agrees that particle size, surface area, crystalline structure, and surface chemistry are important and vital measurements to gauge nanomaterial reactivity [15, 17, 20, 22, 24, 27]. NIOSH's *Approaches to Safe Nanotechnology* explains that there is not a consensus for a standard on how to measure nanomaterial exposure, and thus provides detailed guidance on workplace monitoring [24].

4.3.1 Measurement

There are varying methods and protocols for measuring quantities of nanomaterials. Measurements can be taken in the workers' personal breathing zone (PBZ) or from a static location in the lab [24, 26, 35]. NIOSH's *Approaches to Safe Nanotechnology* and SLAC's *Nanomaterial Safety Plan* prefer measurements be taken in the PBZ rather than in a static location [24, 26]. The European Commission's *The Appropriateness of Existing Methodologies* and IRSST's *Engineered Nanoparticles, Current Knowledge About OHS Risks and Prevention Measures* explain that the best instrumentation for measurement measures concentrations of nanomaterials that pose human health risk and provides an accurate measurement of surface area [25, 27]. IRSST further specifies that personal sampling measurements should be able to distinguish between nanoparticles and dust particles that are in the environment, but does not provide a specific example of how this would be performed [27]. NIOSH and SLAC list a direct-reading particle measuring device, a real-time measurement tool, as a method of analyzing nanomaterial volume [24, 26].

4.3.2 Techniques

Types of sampling are consistent between IRSST and NIOSH, and include the following [24, 27]:

- "Size-fractionated aerosol sampling" [24]
- "Real-time aerosol sampling" [24]
- "Surface-area measurements" [24]
- "Particle number concentration measurement" [24]
- "Surface-area estimation" [24]
- "Particle number concentration mapping" [24]

However, NIOSH's *Approaches to Safe Nanotechnology* specifies key parameters that should be considered when taking sample measurements [24]:

- "Response range of instrumentation" [24]
- "Whether the measurement was personal or taken from a static location" [24]
- "The location of all possible background sources of aerosols" [17, 25, 27]
- Background sources are described as aerosols that are already in the laboratory setting prior to handling nanomaterials [24]

4.3.3 Nanoparticle Emission Assessment Technique (NEAT)

NIOSH's *Approaches to Safe Nanotechnology* has provided a specific technique for assessing emissions of nanoparticles, known as the nanoparticle emission assessment technique (NEAT) [24]. NEAT is intended to estimate initial workplace conditions and identify sources of nanomaterial emissions [24]. Other guidance documents have also recommended techniques similar to the ones listed in NEAT in their recommendations for safe handling.

4.3.4 Establishing Background Levels

Before any measurements are recorded, an industrial hygienist, or other qualified person, should be available to perform an initial assessment of the working environment:

- “Conduct an observational walkthrough survey of the production area and processes to locate potential sources of emissions” [15, 24, 26, 27]
- “Determine the frequency and duration of each operation and the type of equipment used for handling and containment of the material” [24, 27]
- “Determine presence/absence of GEV (general exhaust ventilation) and LEV (local exhaust ventilation) and other engineering controls” [24, 27]
- “Determines the process points where containment is deliberately breached” [20, 24, 27]

The source of nanoparticle emissions should first be identified to determine the background levels of aerosols before any handling of nanomaterials [15, 17, 20, 22, 24, 27]:

- “Potential sources of emissions can be identified by reviewing the type of processes and work practices, assessing process flow, and determining material inputs and discharges” [15, 17, 20, 24, 26]
- “The individual performing these tasks should also document the type of equipment used for handling nanoparticles and identify potential leakage sources likely to promote the emission of nanoparticles” [24, 27]
- “Available literature should be reviewed to understand the nanomaterials that are being produced or used. The individual physicochemical properties of nanomaterials (e.g., size, shape, solubility, and reactivity) should also be understood. Some examples of literature that would include this information are MSDS sheets or records of feedstock materials” [5, 8, 11, 15, 17, 22, 24-27]

Once source of background emissions have been identified, airborne particle concentration sampling should be performed to determine background measurements [24]. Average airborne particle concentration can be determined at various processes and adjacent work areas with the condensation particle counter (CPC) and optical particle counter (OPC) before processing or handling of nanomaterials begins [24]. The measurements of airborne particle concentration and size ranges are made with CPC and OPC simultaneously at locations near the suspected or likely emission source [17, 24, 25, 27]. If the background concentrations are high, an assessment will be made as to whether there may be a source of incidental nanomaterials in the area [17, 19, 24, 27]. The average background concentration will be computed and then subtracted from the measurements made during processing, manufacturing, or handling of nanomaterials [17, 24, 26, 27].

4.3.5 Measuring Airborne Particles

Area air samples (filter-based pair) should be collected for particle analysis via transmission electron microscopy (TEM) if nanomaterials are detected in the process area at elevated concentrations relative to background particle number concentrations [17, 24, 27].

- “Source-specific air samples are collected as close as possible to the suspected emission source but outside of any existing containment” [19, 24, 25, 27]
- “Sampling duration generally matches the length of time in which the potential exposure to the nanomaterial exists at the task or specific process (about 15 to 30 minutes)” [24]
- “If the particle number concentrations are substantially high, then shorter sampling times for the TEM or scanning electron microscope (SEM) sample may be necessary” [24, 27]
- “One sample should be analyzed for elemental mass” [22, 24, 27]
- “One sample should be analyzed by electron microscopy” [24, 27]
- “If measurements obtained with CPC and OPC indicate that nanoparticles are being emitted at a specific process where a worker is located, then the collection of PBZ samples may be warranted” [24, 27]

If surface contamination exists, NEAT also provides guidelines for surface sampling [24]. It is noted that surface sampling is typically not part of the initial assessment of nanomaterials in the workspace and the industrial hygienist or other qualified individual will determine its necessity following these directions [24]:

- “Wear nitrile disposable gloves and properly dispose of them after use” [24]
- “Wipe the surface within a disposable 10 cc x 10 cc template using four horizontal s-shaped strokes” [24]
- “Fold the exposed side of the wipe in and wipe the same area with four vertical s-shaped strokes” [24]
- “Fold the wipe, exposed side in, and place it into a sterile container” [24]

For quality control assurance with sampling techniques, both NIOSH and BSI’s *Guide to Safe Handling* describe the following techniques to ensure quality testing every time [17, 24]:

- “Use factory calibrated direct-reading particle analyzers” [24]
- “Perform daily zero-checks on all particle counters before each use” [24]
- “Calibrate pumps before and after each sampling day” [24]
- “Submit for analysis any process, background, and bulk material samples along with field and media blanks to a lab accredited by the American Industrial Hygiene Association (AIHA)” [24]

4.3.6 Further Information

The following guidance documents provide a comprehensive set of recommendations for monitoring the workplace for nanomaterials:

- NIOSH *Approaches to Safe Nanotechnology* [24] (Pages 71-81)
- IRSST *Engineered Nanoparticles: Current Knowledge about OHS Risks and Prevention Measures* [27] (Page 17-29)

4.4 Wet and Dry Spill Management

Nanotechnology labs that handle dry powder or liquid forms of ENPs inevitably face the risk of nanomaterial spills [1]. DuPont’s *Nano Risk Framework* further suggests that should an accidental spill occur, estimates of materials released from accidental spills are conducted [15]. Wet and dry spills are fundamentally different and require different practices and protocols.

4.4.1 Equipment

Most guidance documents recommend that spills be cleaned up immediately. It is also recommended that laboratories have a spill kit on site that is readily accessible in the event of a wet or dry spill [1, 5]. These documents suggest that a spill kit allows workers

to respond to accidental spills in a timely fashion. Although many documents do not explicitly state that a spill kit should be on-hand, there is consensus on the equipment that should be present in laboratories to mitigate the uncertain health effects of accidental spills. Such equipment includes the following:

- Barricade tape: prevents hazard by increasing the visibility of a spill [1]
- Latex or nitrile gloves (often double-gloved): creates a barrier between the skin and the hazardous spill [1, 7-9, 11, 12]
- Respiratory protection such as disposable N-95 respirators prevents workers from respiring hazardous substances [1, 7-9, 11, 12]. Ellenbecker and Tsai's *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* recommend a specific respirator that has proven effective in filtering nanoparticles (N-95 filtering face piece respirator) [1]
- Absorbent/adsorbent/surfactant material: used to absorb hazardous materials [1, 5, 12]
- HEPA-filtered vacuum: used to eliminate hazardous materials from the workplace [5, 7-9, 11-13, 27]
- Wipes: used to eliminated hazardous materials from the workplace [1, 5, 7-9, 11-13, 24]
- Sealable plastic bags or other tightly closed containers: used to collect spill cleanup materials [1, 5, 7]
- Walk-off mat or Tacky Mat®: used at the exit to reduce the likelihood of spreading nanoparticles [1, 5, 8, 9, 11, 17]

4.4.2 Wet versus Dry

It is important to note the differences in procedure when eliminating wet versus dry spills. HEPA-filtered vacuums and wipes are the two main ways that nanomaterials can be physically picked up and removed from the laboratory. Some guidance documents recommended the use of wipes while others recommend the use of a HEPA-filtered vacuum. It is inferred that an either/or statement is made because a firm may not own a HEPA-filtered vacuum. Other documents, in a more thorough manner, suggest that cleanup procedures may include both a HEPA-filtered vacuum and wipes [1, 11]. Moreover, for both types of spills it is recommended that soaps or cleaning oils and a microfiber cleaning cloths be used [8, 12, 24, 27].

4.4.3 Dry Spills

For dry spills, it is explicitly stated that response workers must not dry-sweep or use compressed air [1, 3, 5-9, 11-14, 17, 20, 26, 27]. Furthermore, it is recommended that HEPA filters are properly tested as directed by the manufacturer and are labeled and used for nanomaterials only [1, 5, 6, 8, 12, 13, 17, 20, 26].

4.4.4 Wet Spills

For wet spills, the goal is to prevent nanomaterial residue once the liquid has been removed [1]. Instead of just having a standard walk-off or Tacky Mat®, it is recommended that the mat have absorbent properties in the event of a wet spill [1, 4, 5, 8, 9, 11, 17, 20]. If using a HEPA-filtered vacuum for wet spills, it is recommended that one vacuum be designated for nanomaterials cleanups only [1, 3, 5, 7-9, 11-14, 17, 20, 26, 27]. Various other specifications for liquid cleanups may be found in the aforementioned guidance documents.

4.4.5 Further Information

The following guidance documents provide a comprehensive set of recommendations for wet and dry spills:

- Ellenbecker and Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 64-67)
- University of New Hampshire *Nanomaterials Safety Program* [12] (Pages 11-12)
- SLAC *Nanomaterial Safety Plan* [26] (Pages 31-32)
- University of California *Nanotechnology: Guidelines for Safe Research Practices* [8] (Page 4)
- LBNL *Control Procedures for Engineered Nanomaterials* [5] (Page 5)
- Stanford University *General Principles and Practices for Working Safely with Engineered Nanomaterials* [7] (Page 7)
- UC Santa Barbara *Laboratory Safety Fact Sheet* [11] (Page 3)
- UC Irvine *Standard Operating Procedure for Working with Carbon Nanotubes* [9] (Page 6)
- British Standards Institute *Part 2: Guide to Safe Handling and Disposal of Manufactured Nanomaterials* [17] (Pages 20-21)
- IRSST *Engineered Nanoparticles: Current Knowledge about OHS Risks and Prevention Measures* [27] (Page 85)

4.5 Waste Management

Guidance documents provide only general recommendations about nanomaterial waste management due to a dearth of scientific information and there are currently no guidelines from the EPA specifically addressing disposal of waste nanomaterials. However, Ellenbecker and Tsai's *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* provides extensive insight into how existing regulations (e.g., the Clean Air Act, the Clean Water Act, etc.) govern engineered nanomaterial wastes in different waste streams [1]. This document should be consulted if your firm is interested in reviewing existing waste disposal regulations with regard to nanomaterials.

There is consensus among guidance documents that more research is necessary to determine whether existing practices for handling, treating, storing, and disposing of bulk forms of solid wastes are appropriate for nanoscale wastes of the same chemicals [1, 20]. The disposal requirements for the base materials should be considered first when characterizing nanomaterials. If the base material is toxic, such as silver or cadmium, the nanoscale waste should be considered toxic and/or hazardous as well. Additionally, if the nanomaterial is embedded in a material considered to be hazardous waste, such as a flammable solvent or acid, the nanoscale waste should be considered as such. Bulk carbon is considered a flammable solid, so even carbon-based nanomaterials should be collected to determine hazardous waste characteristics [6].

4.5.1 What Constitutes Waste?

- For the purpose of waste management, nanomaterial waste streams are generally defined as:
 - Consisting of pure nanomaterials [1, 5-7, 14]
 - Items contaminated with nanomaterials (e.g., wipes, pipettes, culture plates, PPE, etc.) [1, 5-7, 13, 14]
 - Liquid suspensions containing nanomaterials [1, 6, 7]
 - Solid matrices with nanomaterials that are friable or have a nanostructure loosely attached [1, 5-7, 13, 14]
- Wastes resulting from decontamination (e.g., cleaning solutions, rinse waters, rags, PPE) should also be treated as nanomaterial-bearing waste [5, 15, 20, 26].
- Equipment previously used with nanoparticles should be evaluated for potential contamination prior to disposal or reuse for another purpose [9, 11, 14, 15, 26].

- Facility components including exhaust systems and internal filters should be evaluated and cleaned if necessary prior to maintenance, modification, or demolition [8, 9, 11, 12, 14, 15, 26].

4.5.2 Waste Handling

- Most guidance documents on this topic advise against disposal of engineered nanomaterial waste in the regular trash or drain. Instead, nanomaterial waste should be collected in labeled, enclosed, hazardous waste containers with secure caps or covers. The label should include a description of the waste and the words “Contains Nanomaterials” [1, 3, 5-7, 14, 17, 20, 26].
- Paper, wipes, PPE and other items that are contaminated should be collected in a plastic bag or other sealable container; this container should be stored in a fume hood until it is full, then double-bagged, labeled, securely tied or sealed, and disposed of accordingly [1, 3, 5, 6, 13, 20].
- In order to prevent nanomaterial loss into the air and the surrounding environment, you should consider suspending powders in a small volume of non-hazardous liquid [8, 15, 20, 26].
- Many guidance documents recommend controlling the release of toxic nanoparticles into the air by using HEPA filtration [1, 3, 5, 6, 8, 9, 11-14, 19, 20, 22, 24].

4.5.3 Proper Waste Disposal

The following are suggested recommendations for proper waste disposal:

- Consider alternative ways to dispose of waste nanoparticles or to reduce their potential hazards rather than disposing of the nanoparticles into the environment [14, 15].
- Even though some waste particles may not strictly qualify as hazardous waste under current rules, it is necessary to manage any waste in nanomaterials labs or workplaces as though they are hazardous waste [14, 15, 25].
- The disposal of all waste material should comply with applicable Federal, State, and local regulations [9, 17, 24, 27].
- Maintain an inventory of all nanomaterial waste that is shipped off-site; the inventory should include a description of the waste, quantity of the waste, as well as means and location of final disposal [26].

4.5.4 Further Information

The following guidance documents provide a comprehensive set of recommendations for management of waste:

4.5.4.1 Current Regulations:

- Ellenbecker & Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 59-63)

4.5.4.2 What Constitutes Waste:

- Ellenbecker & Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 56-57)
- SLAC *Nanomaterial Safety Plan* [26] (Pages 29-30)
- DOE *Approach to Nanomaterial ES&H* [20] (Pages 18-20)

4.5.4.3 Waste Handling:

- SLAC *Nanomaterial Safety Plan* [26] (Pages 29-30)
- DOE *Approach to Nanomaterial ES&H* [20] (Pages 18-20)

4.5.4.4 Waste Disposal:

- University of Washington *Guidelines for Safety during Nanoparticle Research* [14] (Page 4)
- SLAC *Nanomaterial Safety Plan* [26] (Pages 29-30)
- DOE *Approach to Nanomaterial ES&H* [20] (Pages 18-20)

4.6 Control of Airborne Exposures

Workers may become vulnerable to airborne exposures via inhalation and dermal contact. Exposure risks to workers will vary depending upon how the nanomaterial is being handled and the stage of production of the product [1]. To reduce the risk of contact during nanomaterial handling, certain safety precautions have been recommended. It is important to note that selection of exposure controls vary depending on quantity, physical form, and duration of handling [17, 24]. The best way to manage and reduce the threat to airborne nanomaterial exposure is through engineering controls coupled with the support of administrative controls [1].

4.6.1 Engineering Controls

4.6.1.1 Ventilation

Installing exhaust ventilation in the lab is crucial as it reduces the particle to area ratio in the indoor atmosphere. Specific recommendations for exhaust ventilation are as follows:

- Local exhaust ventilation (LEV) is preferred over general exhaust ventilation (GEV) because GEV does not purify the air, but rather dilutes the amount of nanomaterials present in the workspace and available for worker exposure [1, 3, 5, 6, 8, 12, 14, 19, 20, 24].
- Local exhaust ventilation (LEV) requires the installation of an enclosure and a connected filtered exhaust system [1]. An enclosure has the ability to isolate the handling process by reducing the amount of nanomaterials escaping into the room [1, 3, 5, 6, 8, 9, 11-14, 19, 20, 22, 24].
- Workers should not directly exhaust effluent that is reasonably suspected to contain nanomaterials. Further, all effluent should be passed through a HEPA or ultra low particulate air (ULPA) filter prior to exhausting [1, 5, 7, 19, 20, 22, 26, 27].

4.6.1.2 Fume Hood

A fume hood is one type of local exhaust ventilation system. Two types of fume hood options for your lab are an enclosing hood and an exterior hood [1, 3, 5-7, 9, 11-14, 17]. Enclosing hoods physically enclose the source of contamination while exterior hoods are placed next to the source of contamination [1, 3, 5-7, 9, 11-14, 17].

Ellenbecker & Tsai's *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* provides specific guidelines for hood designs, which are listed below [1]:

- "Minimum width of 4 feet (the wider, the better)" [1]
- "Minimum sash open height of 30 inches" [1]
- "Bottom-front airfoil" [1]
- "Side walls that are smooth, rounded and tapered towards the inside of the sash opening" [1]
- "Sash that is easily movable over its entire range of motion" [1]
- "Sash that holds its position over its entire range of motion" [1]

Hood placement in the laboratory is also an important consideration:

- Hoods should not be located next to any lab entry door or high-traffic location [1]
- The best location for a hood is in the corner of the lab, opposite of the lab entrance [1]
- Hoods should be located more than 5 feet from any HVAC air supply grille (10 feet is preferred) [1]

4.6.1.3 Nanomaterial Handling Under a Hood

Certain practices to minimize exposure to nanomaterials have been researched [1]. One such practice is maintaining the appropriate hood face velocity; this is the linear air velocity in the plane of the fume hood [1]. Details regarding proper handling of nanomaterials under a hood are as follows:

- Every lab should have a procedure for routinely monitoring laboratory fume hood performance [1, 15, 19, 22].
- When working under a hood, users should minimize arm movements and move slowly and carefully [1, 3].
- When nanoparticles are being manipulated, traffic should be minimal in front of the hood [1].
- Fume hood face velocities should be set between 80 and 120 feet per minute [1].

4.6.1.4 Hood Sashes

A hood sash is the movable front window of a hood and is made out of clear safety glass [1]. Concerning hood sashes, the following protocols should be followed [1]:

- During hood set-up the sash should be open [1]
- Equipment should be located at least six inches behind the sash opening [1]
- During hood use the sash should be low to give proper hood face velocity [1]
- When the hood is not in use the sash should be in a low or fully-closed position [1]
- Workers should be aware that when fume hood sashes are at low heights, air currents may pull nanomaterials out of the hood and into the breathing zone [1, 10, 27].
- Keeping hood sashes in a low position is considered a sustainable, energy saving practice [1].

4.6.1.5 Fume Hood Alternatives

If your Company does not wish to purchase a fume hood, there are several alternative options:

- **Glove Box** – Significantly minimizes exposure through use of a fully enclosed box with internal gloves that can be operated externally [1, 3, 5-8, 12, 14, 20, 24, 26].
- **Biosafety Cabinets (BSCs)** – BSCs are much like fume hoods except they contain HEPA filtration, making them safer in terms of environmental protection [1, 3, 5, 6, 12, 14, 26]. BSCs are further broken down into classes, which are discussed in detail in Ellenbecker & Tsai's *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1].
- **Powder Handling Enclosures** – Used specifically for powder handling such as during weighing and manipulation. Powder handling enclosures may have a HEPA filter attached to the exhaust [1-3, 5-7, 9, 14].

When nanoparticle manipulation is too large to fit under a standard fume hood, other ventilation systems may be required. It is recommended that a health and safety office aid in the design of these alternative systems [1, 3, 5, 6, 14, 20, 26].

4.6.2 Administrative Controls—Housekeeping and Work Practices

Reducing exposure in the workplace involves taking routine measures to ensure that exposure risks are kept as low as possible. Certain precautions should be taken to minimize the release of nanomaterials into both the indoor and outdoor environment [1, 12, 14, 20, 24, 26].

4.6.2.1 Cleaning

- Clean potentially contaminated surfaces at the end of each laboratory session [5, 12, 14, 20, 24, 26].
- Identify all surfaces that have come into contact with nanomaterials. These surfaces should be cleaned daily with use of proper cleaning materials such as a HEPA filtered vacuum or wet wipes [1-3, 5, 7-9, 11, 12, 14, 20, 24, 26, 27].
- Vacuums designated for nanomaterial cleanup must be labeled, “For Use With Nanoparticles Only” [1, 5, 12, 13, 20].
- Vacuum dry nanoparticles only if the vacuum cleaner has a tested and certified HEPA filter [1, 5, 7, 12-15, 20, 24, 26].
- Use bench top protective covering material (e.g. Fisher brand® Absorbent Surface Liner) in lieu of HEPA-vacuuming lab bench tops. Material should be disposed of at the end of each day [1, 8, 9, 11, 12].

- Nanoparticles should never be dry swept as this agitation causes them to partially disperse into the air [1, 3, 5, 12, 20, 24].
- Wet-wipe hoods and other lab surfaces at the end of each day; do not allow the build-up of dust [7, 9, 12, 15, 20].
- Adhere to proper nanomaterial waste disposal protocol for your city and state [1-3, 5, 12, 14, 20, 26].

4.6.2.2 Transfer of Nanomaterials

- Transfer nanomaterial samples between workstations in closed, labeled containers [1, 5, 14, 19, 20, 24, 26].
- When transferring nanomaterials outside of the lab, materials should be labeled to indicate their unusual reactivity and toxic potential [7, 19, 20].
- At entry points into designated areas where nanomaterials are handled, post signs indicating hazards, personal protective equipment (PPE) requirements, and administrative control requirements [13, 15, 19, 20, 26].

4.6.2.3 Safe Handling

- Do not allow nanoparticles or nanoparticle-containing materials to come into contact with the skin [1, 7, 9, 14, 20].
- If nanoparticle powders must be handled outside of a ventilated enclosure, use appropriate respiratory protection [1, 9, 11-14, 24, 27].
- Exercise caution when handling nanomaterial-bearing waste [1, 11, 12, 15, 26].
- Designate and label nanoparticle workspaces and storage areas [2, 5, 13, 14, 20].

4.6.2.4 Maintenance

- Enclosed systems under positive pressure must be used in a negative pressure enclosure and exhausted prior to opening [19, 20, 26].
- Maintenance on reactor parts that might cause the release of residual particles should be performed in a fume hood, preferably in a hood with a HEPA filter such as a biosafety cabinet [3, 6, 7, 14, 20, 23, 26].

4.6.3 Respiratory Protection

Many guidance documents note that respiratory protection should be the last line of defense when protecting workers from airborne exposure [1, 2, 6, 8, 10-15, 22, 24, 27]. Ellenbecker & Tsai's *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* provides the following respirator guidelines, followed by other guidance documents that provide similar recommendations [1]:

- Appropriate respirator and cartridge combination (based on EH&S analysis) should be used [24]:
 - N-95 filtering face piece respirators and respirators fitted with HEPA type P-100 filters are highly effective in filtering out nanoparticles [1, 2, 6, 8, 10-14, 20, 22, 24, 27].
 - BSI's *Guide to safe handling and disposal of manufactured nanomaterials* states that high efficiency filters (P3 and FFP3 types) should always be used, not just as a last line of defense [17].
- Personnel that are required to wear a respirator should obtain medical clearance before being fitted [1, 24]. The respirator should be, at a minimum, a half-mask, N-95, or P-100 cartridge type respirator that has been properly fitted [1, 24].
- Personnel that are not required to wear a respirator may wear one at their own discretion [1]. Disposable respirators with at least an N-95 filter rating would be acceptable[1].
- Surgical masks do not count as effective respiratory protection [1].
- If a specific respirator program has been defined further than general recommendations, those should be followed [1, 8, 11, 14, 24]. If there are questions regarding whether a respirator should be used or not, the EH&S office should be contacted for further assistance [8, 11, 14, 24].

Likewise, the United States Occupational Safety and Health Administration (OSHA) provides further program elements that must be met if a respiratory program is to be established:

- An evaluation of the worker's ability to perform [17, 24, 27]
- Regular training of personnel [17, 24, 26, 27]
- Periodic environmental monitoring [15, 24, 26, 27]
- Respirator fit testing [17, 22, 24, 27]
- Respirator maintenance, inspection, cleaning, and storage [17, 22, 24, 27]

4.6.4 Further Information

The following guidance documents provide a comprehensive set of recommendations for controlling airborne exposures:

4.6.4.1 Ventilation:

- Ellenbecker and Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 25-29)

- NIOSH *Approaches to Safe Nanotechnology* [24] (Pages 37-41)

4.6.4.2 Handling Under a Hood:

- Ellenbecker and Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 29-44)

4.6.4.3 Housekeeping:

- Ellenbecker and Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 44-45)
- LBNL *Control Procedures for Engineered Nanomaterials* [5] (Page 2)

4.6.4.4 Work Practices:

- Ellenbecker and Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 45-46)
- DOE *Approach to Nanomaterial ES&H* [20] (Pages 8-9)
- UC Irvine *Standard Operating Procedure for Working with Carbon Nanotubes (CNT)* [9] (Pages 1-2)

4.6.4.5 Respiratory Protection

- Ellenbecker and Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 48-51)
- NIOSH *Approaches to Safe Nanotechnology* [24] (Page 44)

4.7 Control of Dermal Exposures

Intact skin is regarded as relatively impervious to solid materials, acting as a natural defense barrier preventing foreign particles from entering the body. However, research conducted on smaller-sized nanomaterials has indicated solid nanomaterials can penetrate the skin barrier [52]. It has been suggested that certain nanomaterials are small enough to simply pass through skin cell membranes, while larger nanomaterials, aided by their physical properties can also easily, penetrate the skin barrier [25, 52, 53].

4.7.1 Personal Protective Equipment

Nearly every guidance document reviewed recommended some form of PPE to reduce dermal exposure to nanomaterials. However, PPE is at the bottom tier of hierarchical control because it is considered the least effective control for reducing exposure risk. IRSSST's *Engineered Nanoparticles: Current Knowledge about OHS Risks and Prevention Measures* considers PPE to be "used as a last resort, and only when all other means of

control have been implemented without being able to protect the worker adequately” [27]. Guidance documents recommend completing risk characterizations based on the nanomaterial types and the manufacturing processes before choosing which specific personal protective gear is necessary [5, 9, 12, 18, 22, 26, 27]. Ellenbecker and Tsai’s *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* recommends that, for general PPE, workers “wear clothing appropriate for wet chemistry laboratories” [1, 5, 12, 20, 27].

4.7.1.1 Clothing

Clothing should follow basic criteria when worn by workers in areas where nanomaterials are handled:

- “Closed-toed shoes made with low permeability materials” [20]
- “Long pants without cuffs” [20]
- “Long-sleeved shirt” [20]
- “Over-the-shoe booties” [20]
- Lab coats with elastic wrists when handling dry material [10, 20]

IRSST also suggests that disposable clothing be used whenever possible, suggesting specific products from the brand Tyvek® by DuPont, which “may provide adequate skin protection” [27]. Tyvek® materials are made from high-density polyethylene fibers, which are lightweight and water resistant. Early research indicates that Tyvek’s® non-woven polyethylene textile provides a more effective barrier than cotton clothing [54].

The University of New Hampshire’s *Nanomaterials Safety Program* also recommends that “clothing contaminated with nanomaterials should be removed immediate[ly]” and that workers “do not take contaminated clothing home” [12]. The University of New Hampshire further recommends the addition of showering and clothes changing facilities to prevent the inadvertent transfer of nanomaterials to other areas of the workplace or the transfer to items taken home by workers [12].

4.7.1.2 Gloves

Guidance documents typically place the most emphasis on glove criteria when discussing dermal exposure controls. The level of specificity on glove choice, storage, handling, and disposal varies greatly between the guidance documents.

BSI's *Guide to Safe Handling and Disposal of Manufactured Nanomaterials* succinctly explains the following criteria for selecting gloves [17]:

- “Should be appropriate for the risk(s) and conditions where they are to be used” [17]
- “Suitable for the ergonomic requirements and state of health of the intended wearer” [17]
- “Should fit the intended wearer correctly” [17]
- “Should prevent exposure without increasing the overall risk” [17]

The University of New Hampshire claims that “nitrile or rubber gloves which cover hands and wrists completely through overlapping sleeve of lab coat when working with nanomaterials may provide adequate protection” [12]. The Department of Energy's *Approach to Nanomaterial ES&H* also recommends “gauntlet-type gloves or nitrile gloves with extended sleeves”, but cautions that users should “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” [20]. IRSST's *Engineered Nanoparticles: Current Knowledge About OHS Risks and Prevention Measures* states that “changing the gloves regularly is recommended to minimize the exposure risk” and that “for longer handling, two pairs of gloves can be worn, one on top of the other” [27].

4.7.1.3 Eye Protection

The Department of Energy's *Approach to Nanomaterial ES&H* recommends that for eye protection, the worker wear [20]:

- “Safety glasses with side shields (meeting basic impact resistance of ANSI Z87.1)” [20]
- “Face shields” [20]
- “Chemical splash goggle” [20]
- “Other safety eyewear appropriate to the type and level of hazard” [20]

The Department of Energy also warns users that face shields and safety glasses provide insufficient “protection against unbound, dry materials that could become airborne” [20]. IRSST guidance suggests using respirators with a full face piece because these allow both respiratory and eye protection as well the possibility of wearing contact lenses [27].

4.7.1.4 Disposal for PPE

Guidance from BSI and DOE suggest placing soiled PPE in sealable plastic containers or bags stored in the hood [17, 20]. Such waste containers and bags are to be labeled and disposed of in the manner outlined in the Disposal section of this guide.

4.7.2 Further Information

The following guidance documents provide a comprehensive set of recommendations for controlling skin exposures:

- IRSST *Engineered Nanoparticles: Current Knowledge About OHS Risks and Prevention Measures* [27] (Pages 77-78)
- Department of Energy *Approach to Nanomaterials ES&H* [20] (Pages 9-10)
- University of New Hampshire *Nanomaterials Safety Program* [12] (Pages 10-11)
- British Standards Institute *Guide to Safe Handling and Disposal of Manufactured Nanomaterials* [17] (Pages 12-13)

4.7.2.1 Personal Protective Clothing:

- IRSST *Engineered Nanoparticles: Current Knowledge About OHS Risks and Prevention Measures* [27] (Pages 71, 77)
- Department of Energy *Approach to Nanomaterials ES&H* [20] (Pages 9-10)
- University of New Hampshire *Nanomaterials Safety Program* [12] (Pages 10-11)

4.7.2.2 Gloves:

- IRSST *Engineered Nanoparticles: Current Knowledge About OHS Risks and Prevention Measures* [27] (Pages 77-78)
- Department of Energy *Approach to Nanomaterials ES&H* [20] (Page 10)
- University of New Hampshire *Nanomaterials Safety Program* [12] (Pages 8, 10-12)
- British Standards Institute *Guide to Safe Handling and Disposal of Manufactured Nanomaterials* [17] (Page 12)

4.7.2.3 Eye Protection:

- IRSST *Engineered Nanoparticles: Current Knowledge About OHS Risks and Prevention Measures* [27] (Page 78)
- Department of Energy *Approach to Nanomaterials ES&H* [20] (Page 10)
- University of New Hampshire *Nanomaterials Safety Program* [12] (Page 11)

4.7.2.4 PPE Disposal:

- IRSST *Engineered Nanoparticles: Current Knowledge About OHS Risks and Prevention Measures* [27] (Pages 77-78)
- Department of Energy *Approach to Nanomaterials ES&H* [20] (Page 10)
- British Standards Institute *Guide to Safe Handling and Disposal of Manufactured Nanomaterials* [17] (Page 22)

4.8 Laboratory Labeling & Storage

Information conveying hazards, exposure limitation, waste disposal and handling can be communicated clearly and reduce the incidence of health and environmental problems. However, there are no standardized guidelines for the labeling and storage of nanomaterials. As nanomaterials change during their industrial life cycle, methods for labeling and storing should be modified to convey appropriate EH&S information required during manufacturing, distribution, and usage [17].

4.8.1 Labeling Practices

It is important to communicate with anyone handling nanomaterials how to limit their exposure. Limiting exposure by proper labeling and storage practices is essential to practicing the precautionary principle. Practices for labeling and storing nanomaterials are explained [17]:

- Labeling/storage practices should be based on life-cycle analyses and risk assessments that take into account relevant peer-reviewed eco-toxicology works [15].
- Storage practices should maintain stable conditions and increase prevention of contact with dangerous reactants [5].

The Department of Energy's *Approach to Nanomaterial ES&H* provides an example label that they recommend be placed on nanomaterials located in the laboratory (Figure 5) [20]:

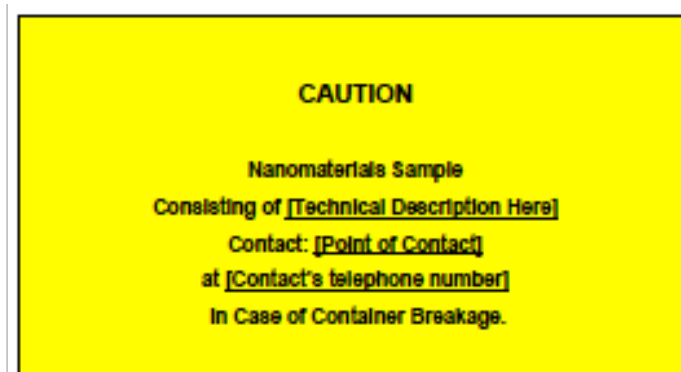


Figure 5: Example of a laboratory label Source: Department of Energy Approach to Nanomaterial ES&H [20]

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” [1, 6, 13, 19, 20, 26].

4.8.2 Traceability

Information regarding the handling of nanomaterials at all stages is important for producers to recall or issue warning notices once nanomaterials have been placed on the market. The following identification information is recommended by BSI’s *Guidance on the labeling of manufactured nanoparticles and products containing manufactured nanoparticles* [17]:

- Designation (type of nanomaterial, trade name)
- Model number
- Production batch
- Serial number
- Date of manufacture

4.8.3 Storage Practices

Due to the risks associated with nanomaterials, it is important to limit exposure as much as possible by employing safe storage practices. Many producers of nanomaterials include Material Safety Data Sheets (MSDS) that specify storage medium, container, temperature range, incompatibility, flammability risks and other important considerations. While it should be noted that many MSDS do not specify if the information is specifically designed for nanomaterials or their parent material, they represent a good starting point to reference when designing more conservative storage

practices [1, 6, 7, 9, 11, 17, 22, 26, 27]. LBNL's *Control Procedures for Engineered Nanomaterials* emphasizes the following safe storage practices [5]:

- Avoid placing incompatible chemicals next to one another to avoid combustion or other dangerous reactions [5]
- If the nanomaterial is present in a solution, considering the properties of the solvent [5]
- Place nanomaterials in an environment free of temperature and humidity extremes [5]
- Use air-impermeable storage containers [5]
- If nanomaterial is light sensitive, avoid contact with light by placing in a dark storage area [5]
 - Placement of nanomaterial in an amber colored jar that is not permeable by light will also help avoid photolysis [5]

4.8.4 Further Information

The following guidance documents provide a comprehensive set of recommendations for labeling and storing nanomaterials:

- British Standards Institute *Guidance on the labelling of manufactured nanoparticles and products containing manufactured nanoparticles* [16] (Entire Document)
- Stanford University *General Principles and Practices for Working Safely with Engineered Nanomaterials* [7] (Page 4)
- DuPont *NANO Risk Framework* [15] (Pages 67-71)
- Department of Energy *Approach to Nanomaterials ES&H* [20] (Pages 8-9)

4.9 Consumer Product Labeling

Nanomaterials are currently being used in many consumer products including crack-resistant paints, transparent sunscreens, scratchproof eye glasses, and stain-repellent fabrics [25]. According to BSI's *Guidance on the Labeling of Manufactured Nanoparticles and Products Containing Manufactured Nanoparticles*, in 2007 there were over 500 consumer products in the worldwide marketplace that could be described as "nanotechnology based" [16]. Labels allow businesses to communicate with their consumers, keeping them aware of opportunities, risks, and uncertainties associated with nanomaterials. Despite the need for adequate consumer product labels, guidance documents tend to focus on laboratory labeling rather than consumer product labeling.

Furthermore, best labeling practices for consumer products are not always explicitly stated, and can be masked under various headings such as “Engineering practices” and “Administrative Controls”. This section explains which documents provide the most comprehensive recommendations, as well as where to find recommendations for particular consumer product labeling practices.

Product labeling is necessary to:

1. Help consumers may make informed decisions about the products they purchase [16]
2. Maintain the transparency of companies manufacturing products containing nanomaterials [16]

4.9.1 Products to Label

Guidance documents drafted by Stanford, BSI and the EU agree that the term “nano” should only be used on product labels if the product contains manufactured nanoscale entities or produces a nano-enabled effect [7, 16, 22]. A nano-enabled effect describes a product that does not contain nanomaterials but has a final effect that is enabled through the use of nanomaterials [7, 16, 22]. Further, it is recommended that those products that do produce a nano-enabled effect include a description of how the effect is achieved.

4.9.2 Label Information

BSI’s *Guidance on the Labelling of Manufactured Nanoparticles and Products Containing Manufactured Nanoparticles* identifies information that should be included in consumer products that contain nanomaterials [16]:

Product Label Suggestions:
“Contains manufactured nanoparticles” [16]
“This product contains manufactured nanoparticles” [16]
“Contains manufactured nanoparticles of X [chemical substance]” [16]
“This product contains manufactured nanoparticles of X” [16]
“Contains 0.1g nanoparticles of X” [16]

“Contains a dispersion of manufactured nanoparticles of X in Y” [16]

“Titanium dioxide, size range X nm-Y nm, specific surface area Zm^2g^{-1} ” [16]

- Clearly label instructions on “labels permanently attached to the product” or package “if any different handling, maintenance, cleaning, storage, or disposal of the product is advised as a consequence of nanoparticles content” [16]
- Include information to “maximize and simplify the traceability of products containing manufactured nanoparticles (PCMNPs)” [16]

4.9.3 Further Information

The following guidance documents provide a comprehensive set of recommendations for labeling consumer products:

- British Standards Institute *Guidance on the labelling of manufactured nanoparticles and products containing manufactured nanoparticles* [16] (Entire Document)
- Stanford University *General Principles and Practices for Working Safely with Engineered Nanomaterials* [7] (Page 4)

4.9.3.1 Products to Label:

- British Standards Institute *Guidance on the labelling of manufactured nanoparticles and products containing manufactured nanoparticles* [16] (Page 5)

4.9.3.2 Label Information:

- British Standards Institute *Guidance on the labelling of manufactured nanoparticles and products containing manufactured nanoparticles* [16] (Pages 6-12)

5. Economic Evaluation

Economic Implications of Implementation			
Equipment	Specification	Range of cost (\$)	Reference
Size Selective Static Sampler	CASELLA Microdust Pro real time aerosol monitor kit	3956-5070	http://www.megadepot.com/product/view/product/asella-176170d-dust-detective-enclosure-for-microdust-pro#176170D
TEOM (Tapered Element Oscillating Microbalance)	1405-F TEOM, Continuous Ambient Air Monitor	\$26000/piece	http://www.thermoscientific.com/wps/portal/ts/products/detail?productId=11960554&groupType=PRODUCTION&searchType=0
ELPI (TM) (Electrical Low Pressure Impactor)	Electrical Low Pressure ELPI™ (Dekati Ltd.)	\$80000/piece	http://www.particleinstruments.com/products_measurement_aerosolsize.html
NanoRanger™ DMA (NanoEngineering Corporation)	NanoRanger™ DMA (NanoEngineering Corporation)	\$50000/piece	http://www.particleinstruments.com/products_measurement_aerosolsize.html
MOUDI (Micro-Orifice Uniform Deposit Impactor)	125-NR NanoMOUDI-II	\$30000/piece	http://www.appliedphysicsusa.com/nanoMOUDI_cascade_impactors.html
DMAS (Differential Mobility Analyzing System)	TSI Electrostatic Classifiers (3080 Series)	See SMPC below	http://www.tsi.com/en-1033/models/2206/3080_series.aspx
CPC (Condensation Particle Counter)	CONDENSATION PARTICLE COUNTER	\$30,000	http://www.tsi.com/en-1033/products/13992/condensation_particle_counter.aspx
OPC (Optical Particle Counter)	OPTICAL PARTICLE SIZER	\$12000 (normally buy 4-10 of these in different in different size range classes)	http://tsi.com/en-1033/products/4294967578/Optical%20Particle%20Sizer%20Model%203330.aspx?gclid=CITW6G0okcCFOQ-bAodOyFkdA
SMPS (Scanning Mobility Particle Sizer)	TSI Scanning Mobility Particle Sizer™ (SMPS™) spectrometer (Includes a suite of DMAS and Diffusion charger)	\$100,000-\$170,000	http://www.tsi.com/uploadedFiles/Product_Information/Literature/Application_Notes/SMPS-002appnote.pdf
Diffusion Charger	Aerosol mobility spectrometry based on diffusion charging	\$1,000	http://www.tsi.com/uploadedFiles/Product_Information/Literature/Posters/UFIPOINNET_EAC07_Hillemann_lecture.pdf
TEM (Transmission Electron Microscope)	LIBRA® 200 FE TEM	\$1.5 - 2 million	http://www.zeiss.com/us/nts
SEM (Scanning Electron Microscope)	EVO® MA 10 SEM	\$100,000 - \$200,000	http://www.zeiss.com/us/nts
Particle Analyzer	Nanotracer Particle Size Analyzer	\$34,000	http://www.microtrac.com/ProductsTechnology/NanotracerParticleSizeAnalyzer.aspx
LEV (Local Exhaust Ventilation)			
GEV (General Exhaust Ventilation)			http://www.chinaqualitylighting.com/wholesaler-hvac_exhaust/
Glove Box	Labconco® PRECISE™ Basic and HEPA-Filtered Glove Boxes	6,265/piece	http://www.coleparmer.com/catalog/product_view.asp?sku=3476300&px="
Glove Bag	Glove Bag™ Inflatable Glove Chambers	295/6 pack	http://www.coleparmer.com/catalog/product_view.asp?sku=0440834&px="
Biological Safety Cabinet Class I	Class I and HEPA Filtered Enclosures	\$5,500	http://www.labconco.com/_scripts/editc25.asp?catid=16
Biological Safety Cabinet Class II	Purifier® Logic® Class II Type A2 Biological Safety Cabinet, 3'W Hood, Fluorescent Light, UV Lights	8,745-10,500/piece	http://www.labsafety.com/Purifier-Logic-Class-II-Type-A2-Biological-Safety-Cabinet-3W-Hood-Fluorescent-Light-UV-Lights_s_155204Ductless-Fume-Hoods-and-Access_28351448/?cl_src=14110944&cl_sku=155204&CID=9PP001 http://www.labcompare.com/General-Laboratory-Equipment/69-Biological-Safety-Cabinet-Biosafety-Cabinet/
Biological Safety Cabinet Class III	Airstream® Class III Biological Safety Cabinet	\$54,000	http://www.bakerco.com/products/class-iii-biosafety-cabinets.html
Snorkel Hood	6'X1500MM EXHAUST VENT SNORKEL	969/piece	http://www.fishersci.com/wps/portal/ITEMDETAIL?itemdetail=%27item%27&productId=11775705&catalogId=29102&matchedCatNo=NC9980636&catCode=SA_SC&endecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15&keepSessionSearchOutPut=true&fromSearch=Y&searchKey=snorkel&highlightProductsItemsFlag=Y
Powder Handling Enclosure	Labconco* XPert* Bulk Powder Enclosures	14,776.30-26,093.35/piece	http://www.fishersci.com/ecomm/servelet/productDetail?storeId=10652&productId=9867174&catalogId=29102&matchedCatNo=10265165 10304163 103061 10265161 10265164 10265156 10304165 10210265160&endecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15&fromSearch=1&searchKey=Handling Powder Enclosure&highlightProductsItemsFlag=Y

Engineering Controls

Equipment	Specification	Range of cost (\$)	Reference
Ghost Wipes	Ghost Wipe Lead Dust Wipe	\$40.50/200	http://www.emssales.net/store/cart.php?m=product_detail&p=620
HEPA Vacuum	HEPA Vacuum	769-1,720/piece	http://www.industrialvac.com/category_s/5.htm?gclid=CM2arv_JoqcCFQVsgwodthwmCg
Smoke Detectors	First Alert Smoke Alarm	6-16/piece	http://www.google.com/search?q=smoke+detector&ie=utf-8&oe=utf-8&aq=&rls=org.mozilla:en-US:official&client=firefox-a#q=smoke+detector&hl=en&client=firefox-a&hs=2mW&rls=org.mozilla:en-US:official&prmd=lvnsb&source=univ&tbs=shop:1&tbo=u&sa=X&ei=IB1sTKmloX2tgObjP3EAg&ved=0CHwOrQQ&biw=1280&bih=557&bav=on.1.or.&fp=ca3424583e0d5426
Fire Extinguisher (Various Types, p 23)	First Alert Fire Extinguisher	15-59/piece	http://www.google.com/search?q=fire+extinguisher&ie=utf-8&oe=utf-8&aq=&rls=org.mozilla:en-US:official&client=firefox-a#q=fire+extinguisher&hl=en&client=firefox-a&hs=ZqW&sa=X&rls=org.mozilla:en-US:official&tbs=shop:1.brand:first+alert&prmd=lvnsu&ei=x1sTZCwLor6swOAieWmBA&ved=OCLMBEMEJKAMwEQ&biw=1280&bih=557&bav=on.1.or.&fp=ca3424583e0d5426
Barricade Tape	DO NOT ENTER Barricade Tape	\$4.99/roll	http://www.saraglove.com/Safety-Barricade-Tape-s/69.htm?gclid=CP6l89-p16YCFRBNqwodnW0SGw
Absorbent/Adsorbent/Surfactant Material	SPC* BattleMat* Camouflage Perforated Sorbent Roll	156.15/roll	http://www.fishersci.com/ecommerce/servelet/fsproduct_detail?storeId=10652&productId=768438&catalogId=29102&matchedCatNo=198194&endecaSearchQuery=%23store%3DSafety%23N%3D4294877816%23top%3DSafety_Spill_Control%23pp%3D15&fromSearch=1&searchKey=walk off Mat&highlightProductsItemsFlag=Y
Wipes	Contec* Polynit Heatseal P.A.T Wipes	101.04/pack of 150	http://www.fishersci.com/ecommerce/servelet/fsproduct_detail?storeId=10652&productId=1175534&catalogId=29102&matchedCatNo=19170931 19170934 191932 19170930 19170933&endecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15&fromSearch=1&searchKey=wipe Wipes&highlightProductsItemsFlag=Y
Tacky Mat	Purus* Cleanroom Tacky Mats	200-340/case of 8	http://www.fishersci.com/ecommerce/servelet/fsproduct_detail?storeId=10652&productId=677045&catalogId=29102&matchedCatNo=19125802 19125814 191817 19125839 19125830 19125823 19125811 1919125805 19125833 19125808 19125836 191258ndecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15&fromSearch=1&searchKey=mats Tacky Mat&highlightProductsItemsFlag=Y
Walk-Off Mat	Fisherbrand* Hard Surface Adhesive Mats	135-286/case of 4	http://www.fishersci.com/ecommerce/servelet/fsproduct_detail?storeId=10652&productId=5002115&catalogId=29102&matchedCatNo=19181518 19181520 191819181517 19181516&endecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15&fromSearch=1&searchKey=mats Tacky Mat&highlightProductsItemsFlag=Y
Fisherbrand Absorbent Surface Liner	Fisherbrand* Absorbent Surface Liners	264.19/case of 4	http://www.fishersci.com/ecommerce/servelet/fsproduct_detail?storeId=10652&productId=743547&catalogId=29102&matchedCatNo=1412746 1412747&endecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15&fromSearch=1&searchKey=Surface Liner absorbents surfaces Absorbent liners&highlightProductsItemsFlag=Y

Administrative Controls

Equipment	Specification	Range of cost (\$)	Reference
Disposable Filtering Facepiece	SELTS 3M N95 and P95 Filtering Facepiece Respirators; No Face Seal (NIOSH-approved)	1-5/piece	http://www.fishersci.com/wps/portal/SEARCHRESULTS?keyword=SELTS+3M+N95+and+P95+Filtering+Facepiece+Respirators&restrictedCategoryId=N-0&Nik=all&ppp=&supCatNoOnOff=&imagesOnOff=&highlightOnOff=&teaserOnOff=&store=Scientific&type=&showAdvanceOptions=
Elastomeric Half-Facepiece	3M(tm) Small Thermoplastic Elastomer 6000 Series Half Facepiece Air Purifying Respirator With Two 3M(tm) 2091 P100 Particulate Filters	20-30/piece	http://www.prosafetysupplies.com/product/3M6191/3Mtm-Small-Thermoplastic-Elastomer-6000-Series-Half-Facepiece-Air-Purifying-Respirator-With-Two-3Mtm-2091-P100-Particulate-Filters.html?meta=GBASE&metaCpg=3M6191&utm_source=gbase&utm_medium=CPC&utm_content=&utm_campaign=3M6191
Elastomeric Full-Facepiece	North Safety 54001 Series Full Facepiece	107-350/piece	http://www.google.com/search?q=Elastomeric+Full-Facepiece&ie=utf-8&oe=utf-8&q=&rls=org.mozilla:en-US:official&client=firefox-a#q=Elastomeric+Full-Facepiece&hl=en&client=firefox-a&hs=RAD&rls=org.mozilla:en-US:official&prmd=lvns&source=lnms&tbs=shop:1&ei=NOY8Ta23L0e4sAP0x5TGAw&sa=X&oi=mode_link&cl=mode&cd=5&ved=0CBIO_AUoBA&blw=1280&bih=557&fp=241062ed1d424d73
N-100 Filter (Respirator)	3M OH&ESD 3M OHESD 142-8233 N100 Maint. Free Particulate Respirator; 3M N100 Respirator - Model MMM 8233	8-243/piece	http://www.google.com/#client=psy&hl=en&blw=1003&bih=595&tbs=shop:1&q=3M+Particulate+Respirator%2C+N100&aq=&aqi=&aqj=&aqk=&aqm=&aqn=&aqo=&aqp=&aqr=&aqst=&aqv=&aqw=&aqz=&as_ssp=629e0b4f1c
R-95 Filter	R95 Particulate respirator	2-140/piece	http://www.google.com/#client=psy&hl=en&blw=1003&bih=595&tbs=shop:1&q=Particulate+Respirator%2C+R95&aq=&aqi=&aqj=&aqk=&aqm=&aqn=&aqo=&aqp=&aqr=&aqst=&aqv=&aqw=&aqz=&as_ssp=629e0b4f1c
P-100 Filter	3M Respirator Filters P100	14/pair	http://www.professionalequipment.com/3m-respirator-filters-p100-1-pair-2097/asbestos-testing/?source=pegs&cid=PESEFGL
Nitrile Gloves	Disposable 4 mil Nitrile Exam Gloves Powder Free	\$5/box of 100	http://www.saraglove.com/Disposable-Powder-Free-Nitrile-Gloves-p/85-6185-p.htm
Latex Gloves	Disposable Latex Gloves Powder Free	\$4.29/box of 100	http://www.saraglove.com/Disposable-Latex-Gloves-Powder-Free-p/85-6135.htm
N95 Respirator	MCR NIOSH N95 Approved Particulate Respirator Mask T1200-70-14	13/20 pack	http://bostonindustrial.net/MCR-NIOSH-N95-Approved-Particulate-Respirator/MB001QCXVCA.htm
Anti-Static Shoes	Polyethylene Shoe Covers Blue, Anti Static, Impervious, Non linting	70-73/200 pair	http://www.tasco-safety.com/clothing/Sunsoft-impervious-boot-covers.html#t1200-70-14?ezppc=froogle
Tyvek by DuPont	DuPont Disposable Elastic Wrist, Ankle & Hood White Tyvek	4.99-196.25/piece	http://www.google.com/search?q=tyvek&ie=utf-8&oe=utf-8&q=&rls=org.mozilla:en-US:official&client=firefox-a#q=tyvek+coveralls&hl=en&client=firefox-a&rls=org.mozilla:en-US:official&prmd=lvns&source=univ&tbs=shop:1&bo=u&sa=X&ei=lo5lTeqFCIz6sAPQodl6BQ&sq=2&ved=0CEkQrOQ&blw=1280&bih=557&bav=1,or,&fp=ca3424583e0d5426
Over the Shoe Booties	DSC Haz Mat Booties	11.90/pair	http://www.fishersci.com/ecomm/servelet/productDetail?storeId=10652&productId=766959&catalogId=29102&matchedCatNo=19049315 19049317 190547 19049316 19059621&endecaSearchQuery=%23ore%3DSafety%23N%3D0%23pp%3D15&fromSearch=1&searchKey=the shoes Booties Over bootie Shoe sho&highlightProductsItemsFlag=Y
Nitrile Gloves with Extended Sleeves	Fisherbrand* Extended Cuff Nitrile Exam Gloves	25.60/pack of 50	http://www.fishersci.com/ecomm/servelet/productDetail?storeId=10652&productId=10208039&catalogId=29102&matchedCatNo=19041170A 19041170D 19041170B 19041170C&endecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15&fromSearch=1&searchKey=Sleeves Nitrile Extended with Gloves&highlightProductsItemsFlag=Y
Gauntlet-Type Gloves	Ansell* Snorkel* PVC-Nitrile Blend Coated Gauntlets	93.03-105.69/dozen	http://www.fishersci.com/ecomm/servelet/productDetail?storeId=10652&productId=619665&catalogId=29102&matchedCatNo=19014903 19014914 190146 19014907 19014904 19120395 19014914&endecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15%23Nao%3D0&fromSearch=1&searchKey=Gauntlet nit glove hand%20protection gauntlets Gloves&highlightProductsItemsFlag=Y
Safety Glasses	3M* Lexa* Safety Eyewear	640.86/100 pieces	http://www.fishersci.com/ecomm/servelet/productDetail?storeId=10652&productId=814272&catalogId=29102&matchedCatNo=19034443 191500144 190339B 19145415 191501323 190334395 1915001434824 19807979 19034441 19034444 19807980 17982 191500142 19807981 190334405 19150132decaSearchQuery=%23store%3DSafety%23N%3D0294876159%23top%3DSafety_Eye+Protection+Products%23pp%3D15&fromSearch=1&searchKey=glasses safety&highlightProductsItemsFlag=Y
Chemical Splash Goggles	Uvex* Futura* Chemical-Splash Goggles	15.60/piece	http://www.fishersci.com/ecomm/servelet/productDetail?storeId=10652&productId=817449&catalogId=29102&matchedCatNo=17987527&endecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15&fromSearch=1&searchKey=goggles chemical spl&highlightProductsItemsFlag=Y

Personal Protective Equipment

5.1 Estimation of Construction Costs for Control Systems and other EH&S infrastructure:

Construction costs for any buildings or infrastructure vary greatly from any given facility handling ENMs. Costs can vary geographically and/or over time for any given amount/type of labor, materials and equipment. Information on construction costs is necessary to implement many EH&S guidance practices described in this guide such as HVAC system recommendations and other important infrastructure.

Fortunately there are industry standards for estimating construction costs that utilize existing data from thousands of construction jobs completed. This data is updated annually and includes descriptive statistics such as productivity rates for each construction project. Lists of vendors are also given with this data specific to each location.

There are several companies that provide this construction data and relevant services for the purposes of cost estimation. Examples of these firms are listed below:

Sweets Construction Cost Estimating Data [55]:

Product/Service Description:

“Labor, materials, and equipment prices have been calculated from the average cost of actual jobs completed in thousands of locations nationwide and presented in CSI MasterFormat -- the industry standard for estimating.

With this valuable resource, you'll be able to calculate overhead, profit, and productivity rates. A handy geographic conversion table is included so making adjustments for local costs is a snap.

Provides contractors, architects, engineers, and all other business professionals the highest available level of precision in predicting construction costs for: sitework, concrete and masonry, woods and plastics, thermal and moisture protection, doors and windows, finishes, specialties, equipment, furnishings, special construction, conveying systems, mechanical systems, and electrical systems.”[55]

RS Means, Reed Construction Data [56]:

Product/Service Description:

“RSMeans is North America's leading supplier of construction cost information. A product line of Reed Construction Data, RSMeans provides accurate and up-to-date cost information that helps owners, developers, architects, engineers, contractors and others to carefully and precisely project and control the cost of both new building construction and renovation projects.

In addition to its collection of annual construction cost data books, RSMeans also offers construction estimating and facilities management seminars, electronic cost databases and software, reference books, and consulting services.”[56]

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10. Appendix II: Abbreviated CERNS



CERNS: A Condensed EH&S Reference for Nanotechnology Startups

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Zoë Layton



Jessica Twining

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Guidance Documents

Documents from Academia

- [In Press] Center for High-Rate Nanomanufacturing: Interim Best Practices for Working with Nanoparticles [1]
- Duke: Working Safely with Nanomaterials in the Laboratory [2]
- Harvard University: Working Safely with Nanomaterials [3]
- Journal of Occupational and Environmental Hygiene: Nanoparticle Usage and Protection Measures in the Manufacturing Industry - A Representative Survey [4]
- Lawrence Berkeley National Laboratory: Control Procedures for Engineered Nanomaterials [5]
- Massachusetts Institute of Technology: EHS Nanomaterials [6]
- Stanford University: General Principles and Practices for Working Safely with Engineered Nanomaterials [7]
- University of California Lab Safety Work Group: Nanotechnology: Guidelines for Safe Research Practices [8]
- University of California, Irvine: Standard Operating Procedure for Working with Carbon Nanotubes (CNT) [9]
- University of California, Los Angeles: Safe Handling of Dry Carbon Nanotube Powder [10]
- University of California, Santa Barbara: Engineered Nanomaterials: Guidelines for Safe Research Practices [11]
- University of New Hampshire: Nanomaterials Safety Program [12]
- University of North Carolina: Summary of Recommended Nanomaterial Risk Levels [13]
- University of Washington: Guidelines for Safety During Nanoparticle Research [14]

Documents from Industry

- DuPont: Nano Risk Framework [15]

Documents from Government

- British Standards Institute: Guidance on the Labeling of Manufactured Nanoparticles and Products Containing Manufactured Nanoparticles [16]
- British Standards Institute: Nanotechnologies - Part 2: Guide to Safe Handling and Disposal of Manufactured Nanomaterials [17]
- Commission of the European Communities: Regulatory Aspects of Nanomaterials [18]
- Department of Energy Notice: The Safe Handling of Unbound Engineered Nanoparticles [19]
- Department of Energy: Approach to Nanomaterial ES&H [20]

- Department of Energy: Secretarial Policy Statement on Nanoscale Safety [21]
- European Risk Observatory Literature Review: Workplace Exposure to Nanoparticles [22]
- National Institute of Occupational Safety & Health: Current Intelligence Bulletin 60 - Interim Guidance for Medical Screening and Hazard Surveillance for Workers Potentially Exposed to Engineered Nanoparticles [23]
- National Institute of Occupational Safety and Health: Managing the Health and Safety Concerns Associated with Engineered Nanomaterials [24]
- Scientific Committee on Emerging and Newly Identified Health Risks: The Appropriateness of Existing Methodologies to Assess the Potential Risk Associated with Engineered and Adventitious Products of Nanotechnologies [25]
- Stanford Linear Accelerator Center: Nanomaterial Safety Plan [26]

Documents from Non-Profit Organizations

- Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail: Engineered Nanoparticles - Current Knowledge about OHS Risks and Prevention Measures [27]

List of Acronyms

AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute
BSC	Biosafety Cabinet
BSI	British Standards Institute
CAA	Clean Air Act
CERNS	A Condensed EH&S Reference for Nanotechnology Startups
CNMS	Center for Nanophase Materials Sciences
CNT	Carbon Nano Tube
CPC	Condensation Particle Counter
CWA	Clean Water Act
DOE	Department of Energy
EH&S	Environmental Health and Safety
ENM	Engineered Nanomaterial
ENP	Engineered Nanoparticle
EU	European Union
FHSA	Federal Hazardous Substances Act
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GEV	General Exhaust Ventilation
HEPA	High-Efficiency Particulate-Absorbing
HVAC	Heating, Ventilating, and Air-Conditioning
IRSST	Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail
ISO	International Organization for Standardization
LBNL	Lawrence Berkeley National Laboratory
LEV	Local Exhaust Ventilation
MSDS	Material Safety Data Sheet
NEAT	Nanoparticle Emission Assessment Technique
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NM	Nanomaterial
OHS	Occupational Health and Safety
OPC	Optical Particle Counter
OSHA	Occupational Safety and Health Administration
PBZ	Personal Breathing Zone
PCMNP	Products Containing Manufactured Nanoparticles
PPE	Personal Protective Equipment
RCRA	Resource Conservation and Recovery Act
REACH	Registration, Evaluation, Authorisation, and Restriction of Chemical Substances
SEM	Scanning Electron Microscopy
SLAC	Stanford Linear Accelerator Center
TEM	Transmission Electron Microscopy

TiO ₂	Titanium Dioxide
TSCA	Toxic Substances Control Act
TURI	Toxics Use Reduction Institute
UC CEIN	University of California Center for Environmental Implications of Nanotechnology
ULPA	Ultra Low Particulate Air
US FDA	United States Food and Drug Administration
US EPA	United States Environmental Protection Agency
UV	Ultraviolet

1. Foreword

When designing an environmental, health and safety (EH&S) program, it is especially important to highlight diversity within the nanotechnology industry. Different types of nanomaterials characterized by a wide array of special properties are developed and/or utilized by different companies. The intention of this guide is to provide a useful synthesis of nanotechnology specific EH&S practices. Contextual knowledge is provided, detailing relevant information about nanomaterial properties, and a brief description of EH&S risks and regulatory developments. This guide is primarily intended for companies seeking to determine adequate practices and EH&S standards while handling nanomaterials. It should be noted that while this guide provides initial guidance about nanomaterial EH&S, it should not be the sole basis for the implementation of programs to address any individual company's EH&S concerns. It may be necessary to develop a specially devised set of EH&S practices with the aid of a professional, such as an industrial hygienist, due to the differences in usage, manufacturing processes, storage environmental and distribution. Further information about specific EH&S practices described in this guide can be found in the reference documents cited.

2. Recommendations

The following recommendations have been extracted from guidance documents of varying sectors: academic, government, industry, and non-profit. The goal was to assess how recommendations compared across the sectors and what was most commonly recommended. We have taken the recommendations directly from guidance documents, with the full name of the guidance document the information was sourced from for you to reference for further information. We have also provided a list of documents that support the recommendations listed in numbers directly following each recommendation. The list of documents with their respective number is listed at the beginning of this document.

If you would like to read the recommendations directly from the documents themselves, we have done the legwork for you. At the end of each section, there is a list of documents with specific page numbers that address each topic. These documents address the topic very clearly and provide adequate information in order to help you make the best decision for your company. Remember, these are neither exhaustive nor absolute lists. There are many guidance documents available to the nano-industry.

2.1 Hierarchy of Nanomaterial Hazardous Control

Nanomaterials have greater potential for exposure and EH&S risks than the same chemical substances composed of larger particles and structures. Therefore, NMs may require a different set of hazard and exposure controls than the controls utilized when handling larger particles and structures of the same substance. In addition to the physical form, several factors influence the selection of exposure controls for NMs, including quantity of NMs handled and task duration [28]. As each of these variables increase, exposure risk becomes greater as does the need for more efficient exposure control measures (Figure 1 and 2) [24]. For instance, operations involving easily dispersed dry NMs deserve more attention and more stringent controls than those where the NMs are embedded in a solid or suspended in a liquid matrix [1]. Furthermore, NMs in a gas phase pose the greatest risk for inhalation [27]. Liquid nanoparticle suspensions typically offer little opportunity for inhalation exposure during routine operations, but may represent a significant hazard when spilled [1].

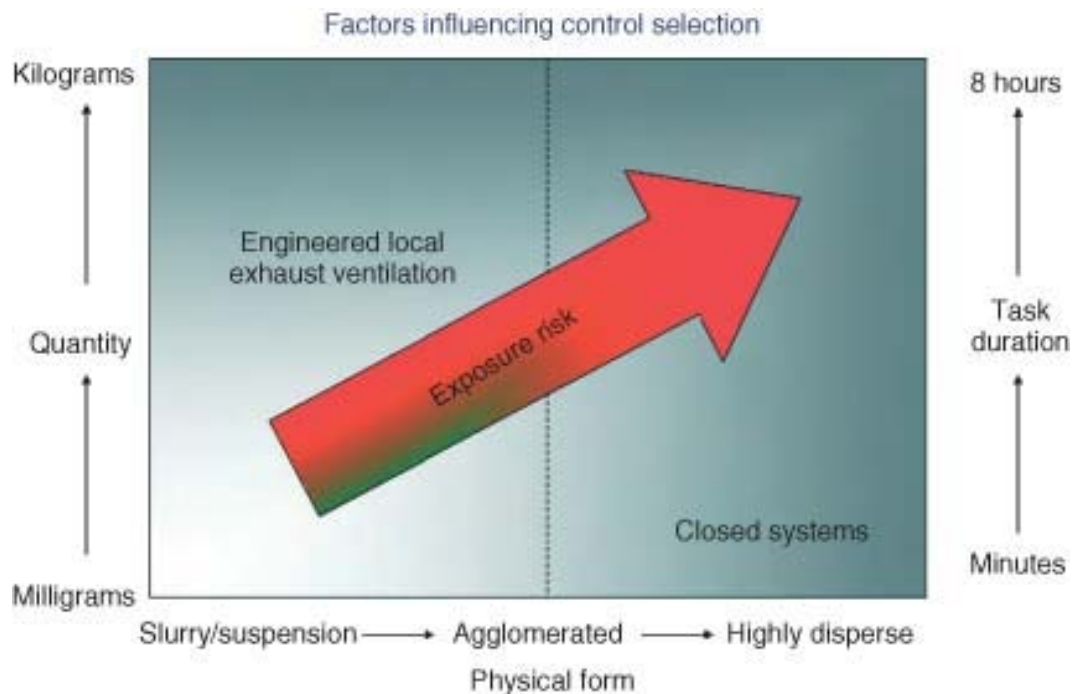


Figure 1: Factors Influencing Control Selection Source: NIOSH Approaches to Safe Nanotechnology [24]

The traditional industrial hygiene hierarchy of exposure controls emphasizes reducing the hazard as close to the source as possible using the following controls:

- Elimination
- Substitution
- Isolation
- Engineering Controls
- Administrative or Work Practice Controls
- Personal Protective Equipment (PPE)

Firms manufacturing and handling NMs could employ this standard hierarchy of hazard controls to reduce hazardous exposures [29].

2.1.1 Elimination Control

The primary example of source control is elimination of the hazard [30]. This approach may be difficult to implement with NMs, which exhibit unique, commercially viable properties that could also cause potential hazards. One approach to reducing the potential toxicity of a given nanoparticle may be to coat the particle with a less hazardous material that still allows the commercial properties to be exhibited. However, the durability of such coatings after the particles enter the environment or the body would need to be evaluated thoroughly [30]. Other examples of elimination control include the use of minimal amounts of nanomaterials, the proper disposal of redundant equipment that contain nanomaterials, the removal of excess quantities of nanomaterials accumulated over time (e.g., in absorbent mats, reactor, biosafety cabinets or other surfaces), and proper waste disposal and spill management [30].

2.1.2 Substitution Control

Substitution refers to replacing high-risk nanomaterials with low or no risk nanomaterials or changing the physical state of the nanomaterial being handled (e.g., using solution instead of powders) [30]. Substitution control could also be changing a process that has a high probability of worker and environmental exposure to a more enclosed process. As an example, nanomaterials in powder form pose greater risk than the same nanomaterial in solution; therefore, processes involving nano-powders can be substituted with less risky nano-solutions or pellets [30]. The US Department of Energy recommends the following order of preference when handling nanomaterials (1 being lowest risk and 4 being highest risk):

1. Solid materials with embedded 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 aggregates

Another option would be to substitute engineered nanoparticles may be replaced with naturally occurring nanoparticles. For instance, Xia *et al.* (2010) compared isolated organic nanoparticles from English Ivy (*Hedera helix*) with titanium dioxide (TiO₂) nanoparticles contained in some sunscreens [31]. The ivy nanoparticles were more efficient in blocking UV light, less toxic to mammalian cells, easily biodegradable, and had a limited potential to penetrate human skin. These results indicate that the organic nanomaterial provides a safer alternative for both workers and consumers than the metal nanoparticles currently used by sunscreen makers. The effectiveness of substitution control is dependent on the choice of replacement.

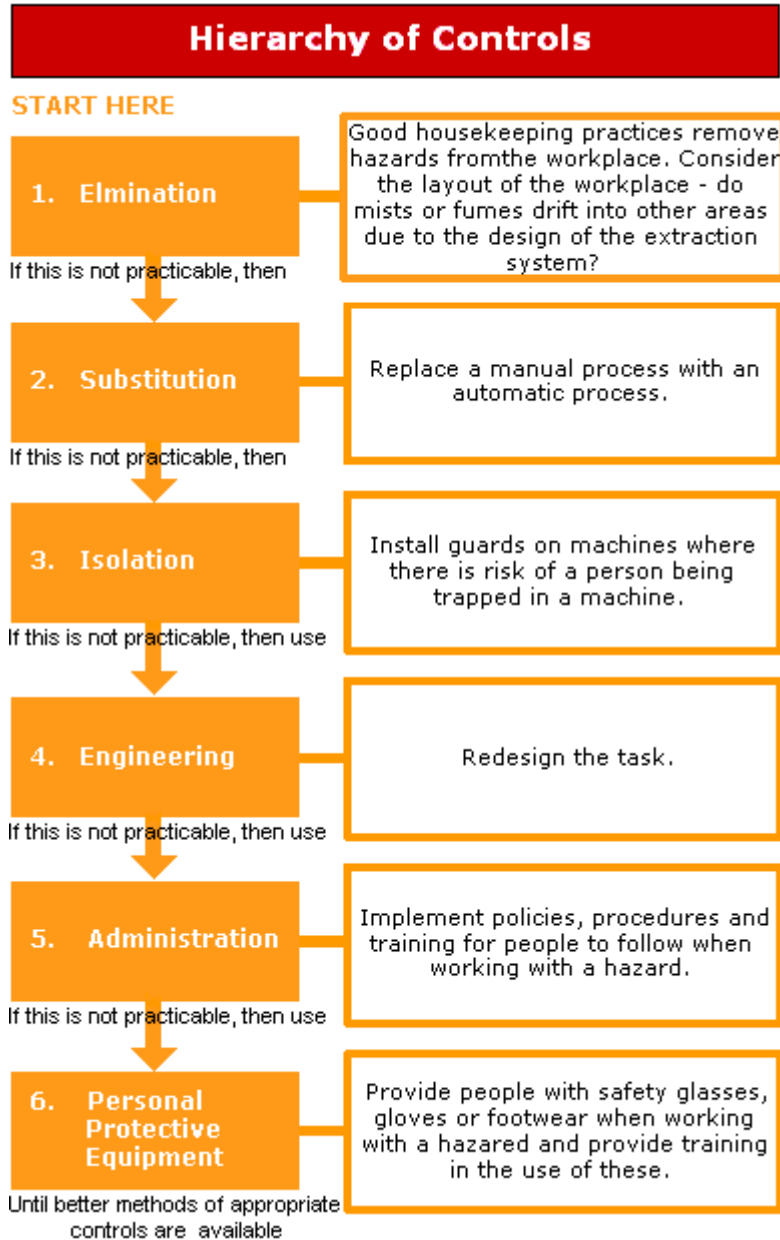


Figure 2: Hierarchy of Controls Source: SafeWorks SA
<http://www.safework.sa.gov.au/contentPages/images/HierarchyControls2.gif>

2.1.3 Isolation Control

Isolation control involves confining the production or manipulation of nanomaterials to a place (work stations) that only trained workers may access [11]. Nanomaterial

workspaces and storage areas therefore should be designated and labeled as such [5, 13, 19, 20, 26]. Isolation control especially reduces the risk of exposing other workers or visitors to nanomaterials, as these groups of people are often not wearing the necessary PPE. Personnel who do not normally handle NMs, such as equipment or facilities maintenance staff, may still come into contact with nanomaterials. These types of personnel must be warned of the potential hazards of NMs and the precautions they should take to protect themselves if the equipment or facilities cannot be decontaminated before their work [13, 14]. Signs should be posted indicating hazards, personal protective equipment requirements, and administrative control requirements at entry points into designated areas where nanomaterials are handled [13, 19, 20, 26].

2.1.4 Engineering Controls

Engineering controls are practices employed to prevent worker exposure to hazardous materials and activities. Examples of engineering controls include glove boxes and bags, HEPA-filtered biosafety cabinets, and/or other negative-pressure enclosures. The most effective engineering controls are generally practices that provide a high level of control, independent of worker interactions [23]. Enclosures used to perform work with nanomaterials should operate at a negative pressure differential^a compared to the worker's breathing zone [32]. There may be limits to the kind of processes that can be carried out in engineering enclosures. If a process cannot be enclosed, then other engineered systems (e.g., snorkel hood) should be applied to control fugitive emissions of engineered nanomaterials or hazardous precursors that might be released [5, 19, 20, 26].

2.1.5 Administrative Controls

Administrative controls involve changing work procedures and increasing employee awareness through practices such as written safety policies, supervision, and scheduling hazardous jobs outside normal working hours to reduce general exposure. Generally, administrative controls contribute to reducing worker exposures but do not actually modify the work environment [1]. Education and training with the goal of reducing the duration, frequency, and severity of exposure to hazardous chemicals or situations is also an important form of administrative control. Administrative controls may also include custodial practices such as cleaning all surfaces potentially contaminated with NMs at the end of each shift using a HEPA vacuum and/or wet wiping methods. They

^a Negative pressure differential is achieved when air is evacuated from an area, room or hood. Laminar flow or biosafety hoods often use negative pressure to sweep away contaminants from a specific processor in areas where particles and/or other contaminants are being generated.

typically require significant resources to be maintained over long periods of time for continuing levels of effectiveness. They are also generally highly dependent on worker behavior.

2.1.6 Personal Protective Equipment (PPE) Controls

PPE is important in situations in which engineering controls cannot be installed due to the temporary nature of a process, or when engineering controls will not provide sufficient exposure control [28]. When employed by itself, PPE is considered the least reliable form of control, but effectively complements other types of control practices [28]. Appropriate PPE should be worn on a precautionary basis whenever the failure of a single control could entail a significant risk of exposure [1, 3, 9-12, 14]. Hazard evaluation should be conducted to determine PPE appropriate for the level of hazard [5, 9, 12, 18, 20, 22, 26, 27]. Examples of PPE include closed-toed shoes, safety glasses, goggles, gloves, NIOSH-approved N-95 respirators, long sleeve shirts, long pants, and laboratory coats.

2.2 Fire and Explosion Control

Three components are necessary for fire and explosions to occur:

- Combustible materials (e.g., dust particles, wood, metal dusts)
- Substance or gas to cause it to burn (e.g., peroxide, oxygen, air)
- Ignition source (e.g., open flame, heat)

All guidance recommendations pertaining to nanomaterial fire and explosion control address how to eliminate or reduce the components necessary for fire and explosion to occur (Figure 3) [27].

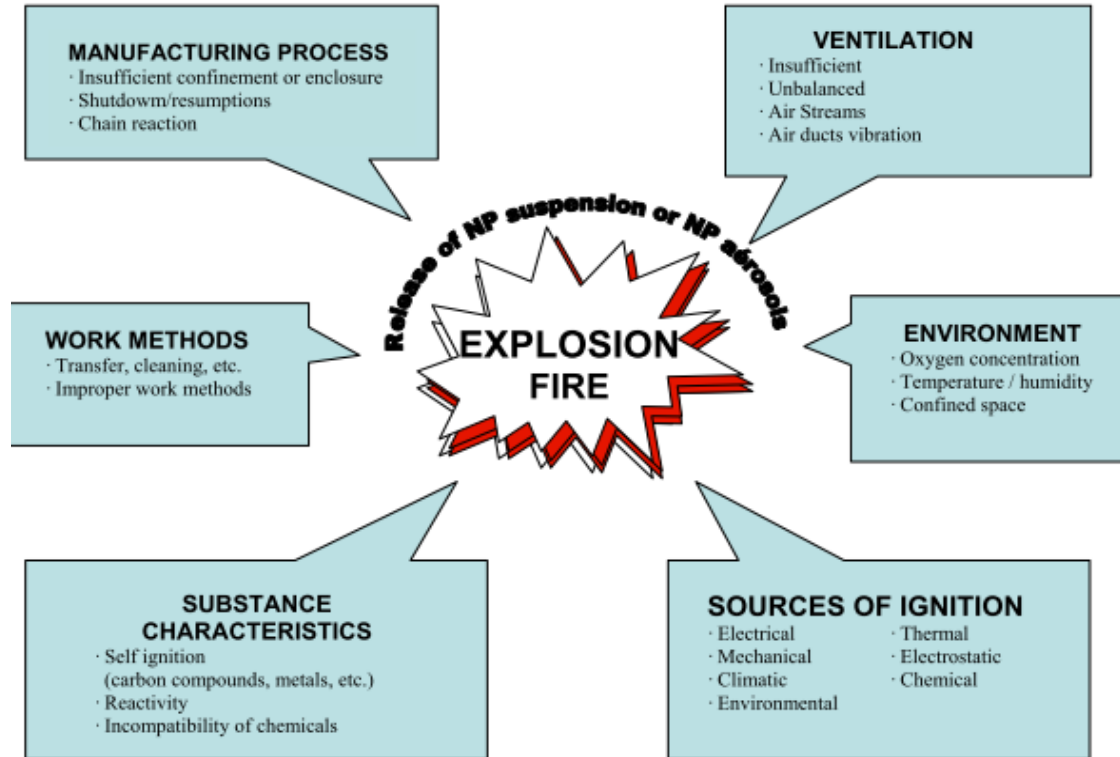


Figure 3: Conditions that increase risk of explosions or fires by engineered nanomaterials Source: IRSST’s *Engineered Nanoparticles, Current Knowledge About OHS Risks and Prevention Measures* [27]

2.2.1 Identify Fire Risk

IRSST’s *Engineered Nanoparticles, Current Knowledge About OHS Risks and Prevention Measures* specifically lists five steps in identifying fire risk potential [27]:

- “Identify and characterize the products likely to produce fires (physical state and physicochemical characteristics)” [27]
- “Know the conditions of storage and use of the substances: temperature, volume, type and tightness of the containers, ventilation, access control, separation of the products, lighting, construction materials, etc.” [27]
- “Know the environmental conditions where the nanomaterials are handled” [27]
- Quantify the amount of material stored, handled, and transported [27]
- Identify possible sources of ignition (e.g., open flames, electrical equipment, heat from reactions) [27]

2.2.2 Reduce Fire Risk and Control for Explosion

The following list is a set of general guidelines taken directly from IRSST's *Engineered Nanoparticles, Current Knowledge About OHS Risks and Prevention Measures* on how to reduce fire risks [27]:

- "Use dustproof mechanical and electrical equipment whenever possible" [27]
- "Prevent dust accumulation outside the equipment" [27]
- "Prevent dust emissions from open bins and drop points" [27]
- "Maintain the highest workplace maintenance standards" [27]
- "Eliminate the ignition sources" [27]
- "Isolate the risky operations, either by distance or by construction" [27]
- "Install explosion vents on the equipment and buildings" [27]
- "Ensure adequate fire protection" [27]
- "Store these materials in sealed containers or tanks" [27]
- "Handle the materials in closed and sealed tanks or pipe systems" [27]
- "The disposal systems must prevent formation of dust cloud" [27]
- "Train the employees in the risks of combustible dusts and the prevention measures" [27]

2.2.3 Reduce Sources of Ignition

- Wear anti-static shoes to reduce the build-up of static charge, which may ignite nanomaterials [17].
- Perform maintenance on machinery and equipment to ensure they do not generate sparks or excessive heat [27].
- Normally stable compounds captured on HEPA filters may become fire hazards when subject to the increased airflow [20].

2.2.4 Reduce Available Oxidants

- Use controlled-atmosphere production and storage processes, using carbon dioxide, nitrogen, or another inert gas to reduce the risks of fire and deflagration [17].
 - Caution: This system creates the potential hazard of asphyxiation for workers [17].

2.2.5 Contain Combustive Material

- Store nanomaterials properly [27].
- Reduce airborne emissions of materials [27].

- Understand the characteristics of the substance [27].

2.2.6 Prepare for Fire and Explosions Incidents

- Smoke and/or temperature detectors [27]
- Easily accessible exits [27]
- Readily available fire extinguishers [27]
 - Should be chosen based on the types of materials used; needs to consider the potential incompatibilities between the extinguishing (retardant) product and the material that is on fire [27].
 - Example: water and metal dusts react to form hydrogen gas, which easily combusts and can further worsen a fire situation. To extinguish a metal dust fire, IRSST suggests use of chemical powders designed to work in those situations, and to ensure firefighting efforts do not further mobilize the metal dusts to create additional fire risks [27].

2.2.7 Further Information

The following guidance documents provide a comprehensive set of recommendations for fire and explosion control:

- IRSST *Engineered Nanoparticles, Current Knowledge About OHS Risks and Prevention Measures* [27] (Pages 34-37, 79-83)
- British Standards Institute *Part 2: Guide to Safe Handling and Disposal of Manufactured Nanomaterials* [17] (Page 13)
- NIOSH *Approaches to Safe Nanotechnology* [24] (Page 21)

2.3 Workplace Monitoring (Exposure Assessment and Characterization)

Standard laboratory practice quantifies nanomaterials through mass measurements. Most guidance agrees that particle size, surface area, crystalline structure, and surface chemistry are important and vital measurements to gauge nanomaterial reactivity [15, 17, 20, 22, 24, 27]. NIOSH's *Approaches to Safe Nanotechnology* explains that there is not a consensus for a standard on how to measure nanomaterial exposure, and thus provides detailed guidance on workplace monitoring [24].

2.3.1 Measurement

There are varying methods and protocols for measuring quantities of nanomaterials. Measurements can be taken in the workers' personal breathing zone (PBZ) or from a static location in the lab [24, 26, 33]. NIOSH's *Approaches to Safe Nanotechnology* and SLAC's *Nanomaterial Safety Plan* prefer measurements be taken in the PBZ rather than in a static location [24, 26]. The European Commission's *The Appropriateness of Existing Methodologies* and IRSST's *Engineered Nanoparticles, Current Knowledge About OHS Risks and Prevention Measures* explain that the best instrumentation for measurement measures concentrations of nanomaterials that pose human health risk and provides an accurate measurement of surface area [25, 27]. IRSST further specifies that personal sampling measurements should be able to distinguish between nanoparticles and dust particles that are in the environment, but does not provide a specific example of how this would be performed [27]. NIOSH and SLAC list a direct-reading particle measuring device, a real-time measurement tool, as a method of analyzing nanomaterial volume [24, 26].

2.3.2 Techniques

Types of sampling are consistent between IRSST and NIOSH, and include the following [24, 27]:

- "Size-fractionated aerosol sampling" [24]
- "Real-time aerosol sampling" [24]
- "Surface-area measurements" [24]
- "Particle number concentration measurement" [24]
- "Surface-area estimation" [24]
- "Particle number concentration mapping" [24]

However, NIOSH's *Approaches to Safe Nanotechnology* specifies key parameters that should be considered when taking sample measurements [24]:

- "Response range of instrumentation" [24]
- "Whether the measurement was personal or taken from a static location" [24]
- "The location of all possible background sources of aerosols" [17, 25, 27]
- Background sources are described as aerosols that are already in the laboratory setting prior to handling nanomaterials [24]

2.3.3 Nanoparticle Emission Assessment Technique (NEAT)

NIOSH's *Approaches to Safe Nanotechnology* has provided a specific technique for assessing emissions of nanoparticles, known as the nanoparticle emission assessment technique (NEAT) [24]. NEAT is intended to estimate initial workplace conditions and identify sources of nanomaterial emissions [24]. Other guidance documents have also recommended techniques similar to the ones listed in NEAT in their recommendations for safe handling.

2.3.4 Establishing Background Levels

Before any measurements are recorded, an industrial hygienist, or other qualified person, should be available to perform an initial assessment of the working environment:

- “Conduct an observational walkthrough survey of the production area and processes to locate potential sources of emissions” [15, 24, 26, 27]
- “Determine the frequency and duration of each operation and the type of equipment used for handling and containment of the material” [24, 27]
- “Determine presence/absence of GEV (general exhaust ventilation) and LEV (local exhaust ventilation) and other engineering controls” [24, 27]
- “Determines the process points where containment is deliberately breached” [20, 24, 27]

The source of nanoparticle emissions should first be identified to determine the background levels of aerosols before any handling of nanomaterials [15, 17, 20, 22, 24, 27]:

- “Potential sources of emissions can be identified by reviewing the type of processes and work practices, assessing process flow, and determining material inputs and discharges” [15, 17, 20, 24, 26]
- “The individual performing these tasks should also document the type of equipment used for handling nanoparticles and identify potential leakage sources likely to promote the emission of nanoparticles” [24, 27]
- “Available literature should be reviewed to understand the nanomaterials that are being produced or used. The individual physicochemical properties of nanomaterials (e.g., size, shape, solubility, and reactivity) should also be understood. Some examples of literature that would include this information are MSDS sheets or records of feedstock materials” [5, 8, 11, 15, 17, 22, 24-27]

Once source of background emissions have been identified, airborne particle concentration sampling should be performed to determine background measurements [24]. Average airborne particle concentration can be determined at various processes and adjacent work areas with the condensation particle counter (CPC) and optical particle counter (OPC) before processing or handling of nanomaterials begins [24]. The measurements of airborne particle concentration and size ranges are made with CPC and OPC simultaneously at locations near the suspected or likely emission source [17, 24, 25, 27]. If the background concentrations are high, an assessment will be made as to whether there may be a source of incidental nanomaterials in the area [17, 19, 24, 27]. The average background concentration will be computed and then subtracted from the measurements made during processing, manufacturing, or handling of nanomaterials [17, 24, 26, 27].

2.3.5 Measuring Airborne Particles

Area air samples (filter-based pair) should be collected for particle analysis via transmission electron microscopy (TEM) if nanomaterials are detected in the process area at elevated concentrations relative to background particle number concentrations [17, 24, 27].

- “Source-specific air samples are collected as close as possible to the suspected emission source but outside of any existing containment” [19, 24, 25, 27]
- “Sampling duration generally matches the length of time in which the potential exposure to the nanomaterial exists at the task or specific process (about 15 to 30 minutes)” [24]
- “If the particle number concentrations are substantially high, then shorter sampling times for the TEM or scanning electron microscope (SEM) sample may be necessary” [24, 27]
- “One sample should be analyzed for elemental mass” [22, 24, 27]
- “One sample should be analyzed by electron microscopy” [24, 27]
- “If measurements obtained with CPC and OPC indicate that nanoparticles are being emitted at a specific process where a worker is located, then the collection of PBZ samples may be warranted” [24, 27]

If surface contamination exists, NEAT also provides guidelines for surface sampling [24]. It is noted that surface sampling is typically not part of the initial assessment of nanomaterials in the workspace and the industrial hygienist or other qualified individual will determine its necessity following these directions [24]:

- “Wear nitrile disposable gloves and properly dispose of them after use” [24]
- “Wipe the surface within a disposable 10 cc x 10 cc template using four horizontal s-shaped strokes” [24]
- “Fold the exposed side of the wipe in and wipe the same area with four vertical s-shaped strokes” [24]
- “Fold the wipe, exposed side in, and place it into a sterile container” [24]

For quality control assurance with sampling techniques, both NIOSH and BSI’s *Guide to Safe Handling* describe the following techniques to ensure quality testing every time [17, 24]:

- “Use factory calibrated direct-reading particle analyzers” [24]
- “Perform daily zero-checks on all particle counters before each use” [24]
- “Calibrate pumps before and after each sampling day” [24]
- “Submit for analysis any process, background, and bulk material samples along with field and media blanks to a lab accredited by the American Industrial Hygiene Association (AIHA)” [24]

2.3.6 Further Information

The following guidance documents provide a comprehensive set of recommendations for monitoring the workplace for nanomaterials:

- NIOSH *Approaches to Safe Nanotechnology* [24] (Pages 71-81)
- IRSST *Engineered Nanoparticles, Current Knowledge About OHS Risks and Prevention Measures* [27] (Page 17-29)

2.4 Wet and Dry Spill Management

Nanotechnology labs that handle dry powder or liquid forms of ENPs inevitably face the risk of nanomaterial spills [1]. DuPont’s *Nano Risk Framework* further suggests that should an accidental spill occur, estimates of materials released from accidental spills are conducted [15]. Wet and dry spills are fundamentally different and require different practices and protocols.

2.4.1 Equipment

Most guidance documents recommend that spills be cleaned up immediately. It is also recommended that laboratories have a spill kit on site that is readily accessible in the event of a wet or dry spill [1, 5]. These documents suggest that a spill kit allows workers

to respond to accidental spills in a timely fashion. Although many documents do not explicitly state that a spill kit should be on-hand, there is consensus on the equipment that should be present in laboratories to mitigate the uncertain health effects of accidental spills. Such equipment includes the following:

- Barricade tape: prevents hazard by increasing the visibility of a spill [1]
- Latex or nitrile gloves (often double-gloved): creates a barrier between the skin and the hazardous spill [1, 7-9, 11, 12]
- Respiratory protection such as disposable N-95 respirators prevents workers from respiring hazardous substances [1, 7-9, 11, 12]. Ellenbecker and Tsai's *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* recommend a specific respirator that has proven effective in filtering nanoparticles (N-95 filtering face piece respirator) [1]
- Absorbent/adsorbent/surfactant material: used to absorb hazardous materials [1, 5, 12]
- HEPA-filtered vacuum: used to eliminate hazardous materials from the workplace [5, 7-9, 11-13, 27]
- Wipes: used to eliminated hazardous materials from the workplace [1, 5, 7-9, 11-13, 24]
- Sealable plastic bags or other tightly closed containers: used to collect spill cleanup materials [1, 5, 7]
- Walk-off mat or Tacky Mat®: used at the exit to reduce the likelihood of spreading nanoparticles [1, 5, 8, 9, 11, 17]

2.4.2 Wet versus Dry

It is important to note the differences in procedure when eliminating wet versus dry spills. HEPA-filtered vacuums and wipes are the two main ways that nanomaterials can be physically picked up and removed from the laboratory. Some guidance documents recommended the use of wipes while others recommend the use of a HEPA-filtered vacuum. It is inferred that an either/or statement is made because a firm may not own a HEPA-filtered vacuum. Other documents, in a more thorough manner, suggest that cleanup procedures may include both a HEPA-filtered vacuum and wipes [1, 11]. Moreover, for both types of spills it is recommended that soaps or cleaning oils and a microfiber cleaning cloths be used [8, 12, 24, 27].

2.4.3 Dry Spills

For dry spills, it is explicitly stated that response workers must not dry-sweep or use compressed air [1, 3, 5-9, 11-14, 17, 20, 26, 27]. Furthermore, it is recommended that HEPA filters are properly tested as directed by the manufacturer and are labeled and used for nanomaterials only [1, 5, 6, 8, 12, 13, 17, 20, 26].

2.4.4 Wet Spills

For wet spills, the goal is to prevent nanomaterial residue once the liquid has been removed [1]. Instead of just having a standard walk-off or Tacky Mat®, it is recommended that the mat have absorbent properties in the event of a wet spill [1, 4, 5, 8, 9, 11, 17, 20]. If using a HEPA-filtered vacuum for wet spills, it is recommended that one vacuum be designated for nanomaterials cleanups only [1, 3, 5, 7-9, 11-14, 17, 20, 26, 27]. Various other specifications for liquid cleanups may be found in the aforementioned guidance documents.

2.4.5 Further Information

The following guidance documents provide a comprehensive set of recommendations for wet and dry spills:

- Ellenbecker and Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 64-67)
- University of New Hampshire *Nanomaterials Safety Program* [12] (Pages 11-12)
- SLAC *Nanomaterial Safety Plan* [26] (Pages 31-32)
- University of California *Nanotechnology: Guidelines for Safe Research Practices* [8] (Page 4)
- LBNL *Control Procedures for Engineered Nanomaterials* [5] (Page 5)
- Stanford University *General Principles and Practices for Working Safely with Engineered Nanomaterials* [7] (Page 7)
- UC Santa Barbara *Laboratory Safety Fact Sheet* [11] (Page 3)
- UC Irvine *Standard Operating Procedure for Working with Carbon Nanotubes* [9] (Page 6)
- British Standards Institute *[Part 2: Guide to Safe Handling and Disposal of Manufactured Nanomaterials]* [17] (Pages 20-21)
- IRSST *Engineered Nanoparticles: Current Knowledge about OHS Risks and Prevention Measures* [27] (Page 85)

2.5 Waste Management

Guidance documents provide only general recommendations about nanomaterial waste management due to a dearth of scientific information and there are currently no guidelines from the EPA specifically addressing disposal of waste nanomaterials. However, Ellenbecker and Tsai's *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* provides extensive insight into how existing regulations (e.g., the Clean Air Act, the Clean Water Act, etc.) govern engineered nanomaterial wastes in different waste streams [1]. This document should be consulted if your firm is interested in reviewing existing waste disposal regulations with regard to nanomaterials.

There is consensus among guidance documents that more research is necessary to determine whether existing practices for handling, treating, storing, and disposing of bulk forms of solid wastes are appropriate for nanoscale wastes of the same chemicals [1, 20]. The disposal requirements for the base materials should be considered first when characterizing nanomaterials. If the base material is toxic, such as silver or cadmium, the nanoscale waste should be considered toxic and/or hazardous as well. Additionally, if the nanomaterial is embedded in a material considered to be hazardous waste, such as a flammable solvent or acid, the nanoscale waste should be considered as such. Bulk carbon is considered a flammable solid, so even carbon-based nanomaterials should be collected to determine hazardous waste characteristics [6].

2.5.1 What Constitutes Waste?

- For the purpose of waste management, nanomaterial waste streams are generally defined as:
 - Consisting of pure nanomaterials [1, 5-7, 14]
 - Items contaminated with nanomaterials (e.g., wipes, pipettes, culture plates, PPE, etc.) [1, 5-7, 13, 14]
 - Liquid suspensions containing nanomaterials [1, 6, 7]
 - Solid matrices with nanomaterials that are friable or have a nanostructure loosely attached [1, 5-7, 13, 14]
- Wastes resulting from decontamination (e.g., cleaning solutions, rinse waters, rags, PPE) should also be treated as nanomaterial-bearing waste [5, 15, 20, 26].
- Equipment previously used with nanoparticles should be evaluated for potential contamination prior to disposal or reuse for another purpose [9, 11, 14, 15, 26].

- Facility components including exhaust systems and internal filters should be evaluated and cleaned if necessary prior to maintenance, modification, or demolition [8, 9, 11, 12, 14, 15, 26].

2.5.2 Waste Handling

- Most guidance documents on this topic advise against disposal of engineered nanomaterial waste in the regular trash or drain. Instead, nanomaterial waste should be collected in labeled, enclosed, hazardous waste containers with secure caps or covers. The label should include a description of the waste and the words “Contains Nanomaterials” [1, 3, 5-7, 14, 17, 20, 26].
- Paper, wipes, PPE and other items that are contaminated should be collected in a plastic bag or other sealable container; this container should be stored in a fume hood until it is full, then double-bagged, labeled, securely tied or sealed, and disposed of accordingly [1, 3, 5, 6, 13, 20].
- In order to prevent nanomaterial loss into the air and the surrounding environment, you should consider suspending powders in a small volume of non-hazardous liquid [8, 15, 20, 26].
- Many guidance documents recommend controlling the release of toxic nanoparticles into the air by using HEPA filtration [1, 3, 5, 6, 8, 9, 11-14, 19, 20, 22, 24].

2.5.3 Proper Waste Disposal

The following are suggested recommendations for proper waste disposal:

- Consider alternatives ways to dispose of waste nanoparticles or to reduce their potential hazards rather than disposing of the nanoparticles into the environment [14, 15].
- Even though some waste particles may not strictly qualify as hazardous waste under current rules, it is necessary to manage any waste in nanomaterials labs or workplaces as though they are hazardous waste [14, 15, 25].
- The disposal of all waste material should comply with applicable Federal, State, and local regulations [9, 17, 24, 27].
- Maintain an inventory of all nanomaterial waste that is shipped off-site; the inventory should include a description of the waste, quantity of the waste, as well as means and location of final disposal [26].

2.5.4 Further Information

The following guidance documents provide a comprehensive set of recommendations for management of waste:

2.5.4.1 Current Regulations:

- Ellenbecker & Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 59-63)

2.5.4.2 What Constitutes Waste:

- Ellenbecker & Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 56-57)
- SLAC *Nanomaterial Safety Plan* [26] (Pages 29-30)
- DOE *Approach to Nanomaterial ES&H* [20] (Pages 18-20)

2.5.4.3 Waste Handling:

- SLAC *Nanomaterial Safety Plan* [26] (Pages 29-30)
- DOE *Approach to Nanomaterial ES&H* [20] (Pages 18-20)

2.5.4.4 Waste Disposal:

- University of Washington *Guidelines for Safety during Nanoparticle Research* [14] (Page 4)
- SLAC *Nanomaterial Safety Plan* [26] (Pages 29-30)
- DOE *Approach to Nanomaterial ES&H* [20] (Pages 18-20)

2.6 Control of Airborne Exposures

Workers may become vulnerable to airborne exposures via inhalation and dermal contact. Exposure risks to workers will vary depending upon how the nanomaterial is being handled and the stage of production of the product [1]. To reduce the risk of contact during nanomaterial handling, certain safety precautions have been recommended. It is important to note that selection of exposure controls vary depending on quantity, physical form, and duration of handling [17, 24]. The best way to manage and reduce the threat to airborne nanomaterial exposure is through engineering controls coupled with the support of administrative controls [1].

2.6.1 Engineering Controls

2.6.1.1 Ventilation

Installing exhaust ventilation in the lab is crucial as it reduces the particle to area ratio in the indoor atmosphere. Specific recommendations for exhaust ventilation are as follows:

- Local exhaust ventilation (LEV) is preferred over general exhaust ventilation (GEV) because GEV does not purify the air, but rather dilutes the amount of nanomaterials present in the workspace and available for worker exposure [1, 3, 5, 6, 8, 12, 14, 19, 20, 24].
- Local exhaust ventilation (LEV) requires the installation of an enclosure and a connected filtered exhaust system [1]. An enclosure has the ability to isolate the handling process by reducing the amount of nanomaterials escaping into the room [1, 3, 5, 6, 8, 9, 11-14, 19, 20, 22, 24].
- Workers should not directly exhaust effluent that is reasonably suspected to contain nanomaterials. Further, all effluent should be passed through a HEPA or ultra low particulate air (ULPA) filter prior to exhausting [1, 5, 7, 19, 20, 22, 26, 27].

2.6.1.2 Fume Hood

A fume hood is one type of local exhaust ventilation system. Two types of fume hood options for your lab are an enclosing hood and an exterior hood [1, 3, 5-7, 9, 11-14, 17]. Enclosing hoods physically enclose the source of contamination while exterior hoods are placed next to the source of contamination [1, 3, 5-7, 9, 11-14, 17].

Ellenbecker & Tsai's *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* provides specific guidelines for hood designs, which are listed below [1]:

- "Minimum width of 4 feet (the wider, the better)" [1]
- "Minimum sash open height of 30 inches" [1]
- "Bottom-front airfoil" [1]
- "Side walls that are smooth, rounded and tapered towards the inside of the sash opening" [1]
- "Sash that is easily movable over its entire range of motion" [1]
- "Sash that holds its position over its entire range of motion" [1]

Hood placement in the laboratory is also an important consideration:

- Hoods should not be located next to any lab entry door or high-traffic location [1]
- The best location for a hood is in the corner of the lab, opposite of the lab entrance [1]
- Hoods should be located more than 5 feet from any HVAC air supply grille (10 feet is preferred) [1]

2.6.1.3 Nanomaterial Handling Under a Hood

Certain practices to minimize exposure to nanomaterials have been researched [1]. One such practice is maintaining the appropriate hood face velocity; this is the linear air velocity in the plane of the fume hood [1]. Details regarding proper handling of nanomaterials under a hood are as follows:

- Every lab should have a procedure for routinely monitoring laboratory fume hood performance [1, 15, 19, 22].
- When working under a hood, users should minimize arm movements and move slowly and carefully [1, 3].
- When nanoparticles are being manipulated, traffic should be minimal in front of the hood [1].
- Fume hood face velocities should be set between 80 and 120 feet per minute [1].

2.6.1.4 Hood Sashes

A hood sash is the movable front window of a hood and is made out of clear safety glass [1]. Concerning hood sashes, the following protocols should be followed [1]:

- During hood set-up the sash should be open [1]
- Equipment should be located at least six inches behind the sash opening [1]
- During hood use the sash should be low to give proper hood face velocity [1]
- When the hood is not in use the sash should be in a low or fully-closed position [1]
- Workers should be aware that when fume hood sashes are at low heights, air currents may pull nanomaterials out of the hood and into the breathing zone [1, 10, 27].
- Keeping hood sashes in a low position is considered a sustainable, energy saving practice [1].

2.6.1.5 Fume Hood Alternatives

If your Company does not wish to purchase a fume hood, there are several alternative options:

- **Glove Box** – Significantly minimizes exposure through use of a fully enclosed box with internal gloves that can be operated externally [1, 3, 5-8, 12, 14, 20, 24, 26].
- **Biosafety Cabinets (BSCs)** – BSCs are much like fume hoods except they contain HEPA filtration, making them safer in terms of environmental protection [1, 3, 5, 6, 12, 14, 26]. BSCs are further broken down into classes, which are discussed in detail in Ellenbecker & Tsai's *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1].
- **Powder Handling Enclosures** – Used specifically for powder handling such as during weighing and manipulation. Powder handling enclosures may have a HEPA filter attached to the exhaust [1-3, 5-7, 9, 14].

When nanoparticle manipulation is too large to fit under a standard fume hood, other ventilation systems may be required. It is recommended that a health and safety office aid in the design of these alternative systems [1, 3, 5, 6, 14, 20, 26].

2.6.2 Administrative Controls—Housekeeping and Work Practices

Reducing exposure in the workplace involves taking routine measures to ensure that exposure risks are kept as low as possible. Certain precautions should be taken to minimize the release of nanomaterials into both the indoor and outdoor environment [1, 12, 14, 20, 24, 26].

2.6.2.1 Cleaning

- Clean potentially contaminated surfaces at the end of each laboratory session [5, 12, 14, 20, 24, 26].
- Identify all surfaces that have come into contact with nanomaterials. These surfaces should be cleaned daily with use of proper cleaning materials such as a HEPA filtered vacuum or wet wipes [1-3, 5, 7-9, 11, 12, 14, 20, 24, 26, 27].
- Vacuums designated for nanomaterial cleanup must be labeled, “For Use With Nanoparticles Only” [1, 5, 12, 13, 20].
- Vacuum dry nanoparticles only if the vacuum cleaner has a tested and certified HEPA filter [1, 5, 7, 12-15, 20, 24, 26].
- Use bench top protective covering material (e.g. Fisher brand® Absorbent Surface Liner) in lieu of HEPA-vacuuming lab bench tops. Material should be disposed of at the end of each day [1, 8, 9, 11, 12].

- Nanoparticles should never be dry swept as this agitation causes them to partially disperse into the air [1, 3, 5, 12, 20, 24].
- Wet-wipe hoods and other lab surfaces at the end of each day; do not allow the build-up of dust [7, 9, 12, 15, 20].
- Adhere to proper nanomaterial waste disposal protocol for your city and state [1-3, 5, 12, 14, 20, 26].

2.6.2.2 Transfer of Nanomaterials

- Transfer nanomaterial samples between workstations in closed, labeled containers [1, 5, 14, 19, 20, 24, 26].
- When transferring nanomaterials outside of the lab, materials should be labeled to indicate their unusual reactivity and toxic potential [7, 19, 20].
- At entry points into designated areas where nanomaterials are handled, post signs indicating hazards, personal protective equipment (PPE) requirements, and administrative control requirements [13, 15, 19, 20, 26].

2.6.2.3 Safe Handling

- Do not allow nanoparticles or nanoparticle-containing materials to come into contact with the skin [1, 7, 9, 14, 20].
- If nanoparticle powders must be handled outside of a ventilated enclosure, use appropriate respiratory protection [1, 9, 11-14, 24, 27].
- Exercise caution when handling nanomaterial-bearing waste [1, 11, 12, 15, 26].
- Designate and label nanoparticle workspaces and storage areas [2, 5, 13, 14, 20].

2.6.2.4 Maintenance

- Enclosed systems under positive pressure must be used in a negative pressure enclosure and exhausted prior to opening [19, 20, 26].
- Maintenance on reactor parts that might cause the release of residual particles should be performed in a fume hood, preferably in a hood with a HEPA filter such as a biosafety cabinet [3, 6, 7, 14, 20, 23, 26].

2.6.3 Respiratory Protection

Many guidance documents note that respiratory protection should be the last line of defense when protecting workers from airborne exposure [1, 2, 6, 8, 10-15, 22, 24, 27]. Ellenbecker & Tsai's *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* provides the following respirator guidelines, followed by other guidance documents that provide similar recommendations [1]:

- Appropriate respirator and cartridge combination (based on EH&S analysis) should be used [24]:
 - N-95 filtering face piece respirators and respirators fitted with HEPA type P-100 filters are highly effective in filtering out nanoparticles [1, 2, 6, 8, 10-14, 20, 22, 24, 27].
 - BSI's *Guide to safe handling and disposal of manufactured nanomaterials* states that high efficiency filters (P3 and FFP3 types) should always be used, not just as a last line of defense [17].
- Personnel that are required to wear a respirator should obtain medical clearance before being fitted [1, 24]. The respirator should be, at a minimum, a half-mask, N-95, or P-100 cartridge type respirator that has been properly fitted [1, 24].
- Personnel that are not required to wear a respirator may wear one at their own discretion [1]. Disposable respirators with at least an N-95 filter rating would be acceptable[1].
- Surgical masks do not count as effective respiratory protection [1].
- If a specific respirator program has been defined further than general recommendations, those should be followed [1, 8, 11, 14, 24]. If there are questions regarding whether a respirator should be used or not, the EH&S office should be contacted for further assistance [8, 11, 14, 24].

Likewise, the United States Occupational Safety and Health Administration (OSHA) provides further program elements that must be met if a respiratory program is to be established:

- An evaluation of the worker's ability to perform [17, 24, 27]
- Regular training of personnel [17, 24, 26, 27]
- Periodic environmental monitoring [15, 24, 26, 27]
- Respirator fit testing [17, 22, 24, 27]
- Respirator maintenance, inspection, cleaning, and storage [17, 22, 24, 27]

2.6.4 Further Information

The following guidance documents provide a comprehensive set of recommendations for controlling airborne exposures:

2.6.4.1 Ventilation:

- Ellenbecker and Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 25-29)

- NIOSH *Approaches to Safe Nanotechnology* [24] (Pages 37-41)

2.6.4.2 Handling Under a Hood:

- Ellenbecker and Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 29-44)

2.6.4.3 Housekeeping:

- Ellenbecker and Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 44-45)
- LBNL *Control Procedures for Engineered Nanomaterials* [5] (Page 2)

2.6.4.4 Work Practices:

- Ellenbecker and Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 45-46)
- DOE *Approach to Nanomaterial ES&H* [20] (Pages 8-9)
- UC Irvine *Standard Operating Procedure for Working with Carbon Nanotubes (CNT)* [9] (Pages 1-2)

2.6.4.5 Respiratory Protection

- Ellenbecker and Tsai *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* [1] (Pages 48-51)
- NIOSH *Approaches to Safe Nanotechnology* [24] (Page 44)

2.7 Control of Dermal Exposures

Intact skin is regarded as relatively impervious to solid materials, acting as a natural defense barrier preventing foreign particles from entering the body. However, research conducted on smaller-sized nanomaterials has indicated solid nanomaterials can penetrate the skin barrier [34]. It has been suggested that certain nanomaterials are small enough to simply pass through skin cell membranes, while larger nanomaterials, aided by their physical properties can also easily, penetrate the skin barrier [25, 34, 35].

2.7.1 Personal Protective Equipment

Nearly every guidance document reviewed recommended some form of PPE to reduce dermal exposure to nanomaterials. However, PPE is at the bottom tier of hierarchical control because it is considered the least effective control for reducing exposure risk. IRSSST's *Engineered Nanoparticles: Current Knowledge about OHS Risks and Prevention Measures* considers PPE to be "used as a last resort, and only when all other means of

control have been implemented without being able to protect the worker adequately” [27]. Guidance documents recommend completing risk characterizations based on the nanomaterial types and the manufacturing processes before choosing which specific personal protective gear is necessary [5, 9, 12, 18, 22, 26, 27]. Ellenbecker and Tsai’s *Safe Practices for Working with Engineered Nanomaterials in Research Laboratories* recommends that, for general PPE, workers “wear clothing appropriate for wet chemistry laboratories” [1, 5, 12, 20, 27].

2.7.1.1 Clothing

Clothing should follow basic criteria when worn by workers in areas where nanomaterials are handled:

- “Closed-toed shoes made with low permeability materials” [20]
- “Long pants without cuffs” [20]
- “Long-sleeved shirt” [20]
- “Over-the-shoe booties” [20]
- Lab coats with elastic wrists when handling dry material [10, 20]

IRSST also suggests that disposable clothing be used whenever possible, suggesting specific products from the brand Tyvek® by DuPont, which “may provide adequate skin protection” [27]. Tyvek® materials are made from high-density polyethylene fibers, which are lightweight and water resistant. Early research indicates that Tyvek’s® non-woven polyethylene textile provides a more effective barrier than cotton clothing [36].

The University of New Hampshire’s *Nanomaterials Safety Program* also recommends that “clothing contaminated with nanomaterials should be removed immediate[ly]” and that workers “do not take contaminated clothing home” [12]. The University of New Hampshire further recommends the addition of showering and clothes changing facilities to prevent the inadvertent transfer of nanomaterials to other areas of the workplace or the transfer to items taken home by workers [12].

2.7.1.2 Gloves

Guidance documents typically place the most emphasis on glove criteria when discussing dermal exposure controls. The level of specificity on glove choice, storage, handling, and disposal varies greatly between the guidance documents.

BSI's *Guide to Safe Handling and Disposal of Manufactured Nanomaterials* succinctly explains the following criteria for selecting gloves [17]:

- “Should be appropriate for the risk(s) and conditions where they are to be used” [17]
- “Suitable for the ergonomic requirements and state of health of the intended wearer” [17]
- “Should fit the intended wearer correctly” [17]
- “Should prevent exposure without increasing the overall risk” [17]

The University of New Hampshire claims that “nitrile or rubber gloves which cover hands and wrists completely through overlapping sleeve of lab coat when working with nanomaterials may provide adequate protection” [12]. The Department of Energy's *Approach to Nanomaterial ES&H* also recommends “gauntlet-type gloves or nitrile gloves with extended sleeves”, but cautions that users should “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” [20]. IRSST's *Engineered Nanoparticles: Current Knowledge About OHS Risks and Prevention Measures* states that “changing the gloves regularly is recommended to minimize the exposure risk” and that “for longer handling, two pairs of gloves can be worn, one on top of the other” [27].

2.7.1.3 Eye Protection

The Department of Energy's *Approach to Nanomaterial ES&H* recommends that for eye protection, the worker wear [20]:

- “Safety glasses with side shields (meeting basic impact resistance of ANSI Z87.1)” [20]
- “Face shields” [20]
- “Chemical splash goggle” [20]
- “Other safety eyewear appropriate to the type and level of hazard” [20]

The Department of Energy also warns users that face shields and safety glasses provide insufficient “protection against unbound, dry materials that could become airborne” [20]. IRSST guidance suggests using respirators with a full face piece because these allow both respiratory and eye protection as well the possibility of wearing contact lenses [27].

2.7.1.4 Disposal for PPE

Guidance from BSI and DOE suggest placing soiled PPE in sealable plastic containers or bags stored in the hood [17, 20]. Such waste containers and bags are to be labeled and disposed of in the manner outlined in the Disposal section of this guide.

2.7.2 Further Information

The following guidance documents provide a comprehensive set of recommendations for controlling skin exposures:

- IRSST *Engineered Nanoparticles: Current Knowledge About OHS Risks and Prevention Measures* [27] (Pages 77-78)
- Department of Energy *Approach to Nanomaterials ES&H* [20] (Pages 9-10)
- University of New Hampshire *Nanomaterials Safety Program* [12] (Pages 10-11)
- British Standards Institute *Guide to Safe Handling and Disposal of Manufactured Nanomaterials* [17] (Pages 12-13)

2.7.2.1 Personal Protective Clothing:

- IRSST *Engineered Nanoparticles: Current Knowledge About OHS Risks and Prevention Measures* [27] (Pages 71, 77)
- Department of Energy *Approach to Nanomaterials ES&H* [20] (Pages 9-10)
- University of New Hampshire *Nanomaterials Safety Program* [12] (Pages 10-11)

2.7.2.2 Gloves:

- IRSST *Engineered Nanoparticles: Current Knowledge About OHS Risks and Prevention Measures* [27] (Pages 77-78)
- Department of Energy *Approach to Nanomaterials ES&H* [20] (Page 10)
- University of New Hampshire *Nanomaterials Safety Program* [12] (Pages 8, 10-12)
- British Standards Institute *Guide to Safe Handling and Disposal of Manufactured Nanomaterials* [17] (Page 12)

2.7.2.3 Eye Protection:

- IRSST *Engineered Nanoparticles: Current Knowledge About OHS Risks and Prevention Measures* [27] (Page 78)
- Department of Energy *Approach to Nanomaterials ES&H* [20] (Page 10)
- University of New Hampshire *Nanomaterials Safety Program* [12] (Page 11)

2.7.2.4 PPE Disposal:

- IRSST *Engineered Nanoparticles: Current Knowledge About OHS Risks and Prevention Measures* [27] (Pages 77-78)
- Department of Energy *Approach to Nanomaterials ES&H* [20] (Page 10)
- British Standards Institute *Guide to Safe Handling and Disposal of Manufactured Nanomaterials* [17] (Page 22)

2.8 Laboratory Labeling & Storage

Information conveying hazards, exposure limitation, waste disposal and handling can be communicated clearly and reduce the incidence of health and environmental problems. However, there are no standardized guidelines for the labeling and storage of nanomaterials. As nanomaterials change during their industrial life cycle, methods for labeling and storing should be modified to convey appropriate EH&S information required during manufacturing, distribution, and usage [17].

2.8.1 Labeling Practices

It is important to communicate with anyone handling nanomaterials how to limit their exposure. Limiting exposure by proper labeling and storage practices is essential to practicing the precautionary principle. Practices for labeling and storing nanomaterials are explained [17]:

- Labeling/storage practices should be based on life-cycle analyses and risk assessments that take into account relevant peer-reviewed eco-toxicology works [15].
- Storage practices should maintain stable conditions and increase prevention of contact with dangerous reactants [5].

The Department of Energy's *Approach to Nanomaterial ES&H* provides an example label that they recommend be placed on nanomaterials located in the laboratory (Figure 4) [20]:

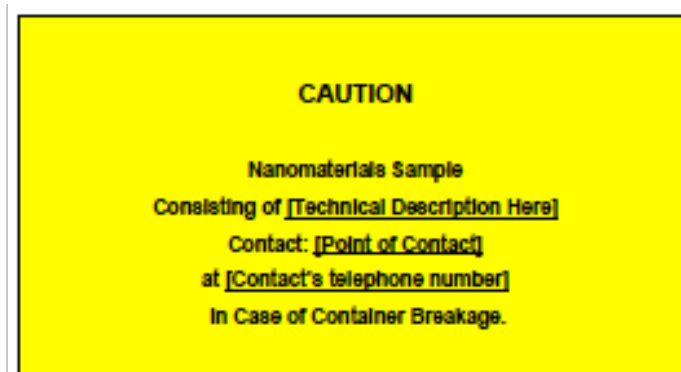


Figure 4: Example of a laboratory label Source: Department of Energy Approach to Nanomaterial ES&H [20]

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” [1, 6, 13, 19, 20, 26].

2.8.2 Traceability

Information regarding the handling of nanomaterials at all stages is important for producers to recall or issue warning notices once nanomaterials have been placed on the market. The following identification information is recommended by BSI’s *Guidance on the labeling of manufactured nanoparticles and products containing manufactured nanoparticles* [17]:

- Designation (type of nanomaterial, trade name)
- Model number
- Production batch
- Serial number
- Date of manufacture

2.8.3 Storage Practices

Due to the risks associated with nanomaterials, it is important to limit exposure as much as possible by employing safe storage practices. Many producers of nanomaterials include Material Safety Data Sheets (MSDS) that specify storage medium, container, temperature range, incompatibility, flammability risks and other important considerations. While it should be noted that many MSDS do not specify if the information is specifically designed for nanomaterials or their parent material, they represent a good starting point to reference when designing more conservative storage

practices [1, 6, 7, 9, 11, 17, 22, 26, 27]. LBNL's *Control Procedures for Engineered Nanomaterials* emphasizes the following safe storage practices [5]:

- Avoid placing incompatible chemicals next to one another to avoid combustion or other dangerous reactions [5]
- If the nanomaterial is present in a solution, considering the properties of the solvent [5]
- Place nanomaterials in an environment free of temperature and humidity extremes [5]
- Use air-impermeable storage containers [5]
- If nanomaterial is light sensitive, avoid contact with light by placing in a dark storage area [5]
 - Placement of nanomaterial in an amber colored jar that is not permeable by light will also help avoid photolysis [5]

2.8.4 Further Information

The following guidance documents provide a comprehensive set of recommendations for labeling and storing nanomaterials:

- British Standards Institute *Guidance on the labelling of manufactured nanoparticles and products containing manufactured nanoparticles* [16] (Entire Document)
- Stanford University *General Principles and Practices for Working Safely with Engineered Nanomaterials* [7] (Page 4)
- DuPont *NANO Risk Framework* [15] (Pages 67-71)
- Department of Energy *Approach to Nanomaterials ES&H* [20] (Pages 8-9)

2.9 Consumer Product Labeling

Nanomaterials are currently being used in many consumer products including crack-resistant paints, transparent sunscreens, scratchproof eye glasses, and stain-repellent fabrics [25]. According to BSI's *Guidance on the Labeling of Manufactured Nanoparticles and Products Containing Manufactured Nanoparticles*, in 2007 there were over 500 consumer products in the worldwide marketplace that could be described as "nanotechnology based" [16]. Labels allow businesses to communicate with their consumers, keeping them aware of opportunities, risks, and uncertainties associated with nanomaterials. Despite the need for adequate consumer product labels, guidance documents tend to focus on laboratory labeling rather than consumer product labeling.

Furthermore, best labeling practices for consumer products are not always explicitly stated, and can be masked under various headings such as “Engineering practices” and “Administrative Controls”. This section explains which documents provide the most comprehensive recommendations, as well as where to find recommendations for particular consumer product labeling practices.

Product labeling is necessary to:

1. Help consumers may make informed decisions about the products they purchase [16]
2. Maintain the transparency of companies manufacturing products containing nanomaterials [16]

2.9.1 Products to Label

Guidance documents drafted by Stanford, BSI and the EU agree that the term “nano” should only be used on product labels if the product contains manufactured nanoscale entities or produces a nano-enabled effect [7, 16, 22]. A nano-enabled effect describes a product that does not contain nanomaterials but has a final effect that is enabled through the use of nanomaterials [7, 16, 22]. Further, it is recommended that those products that do produce a nano-enabled effect include a description of how the effect is achieved.

2.9.2 Label Information

BSI’s *Guidance on the Labelling of Manufactured Nanoparticles and Products Containing Manufactured Nanoparticles* identifies information that should be included in consumer products that contain nanomaterials [16]:

Product Label Suggestions:
“Contains manufactured nanoparticles” [16]
“This product contains manufactured nanoparticles” [16]
“Contains manufactured nanoparticles of X [chemical substance]” [16]
“This product contains manufactured nanoparticles of X” [16]
“Contains 0.1g nanoparticles of X” [16]

“Contains a dispersion of manufactured nanoparticles of X in Y” [16]

“Titanium dioxide, size range X nm-Y nm, specific surface area Zm^2g^{-1} ” [16]

- Clearly label instructions on “labels permanently attached to the product” or package “if any different handling, maintenance, cleaning, storage, or disposal of the product is advised as a consequence of nanoparticles content” [16]
- Include information to “maximize and simplify the traceability of products containing manufactured nanoparticles (PCMNPs)” [16]

2.9.3 Further Information

The following guidance documents provide a comprehensive set of recommendations for labeling consumer products:

- British Standards Institute *Guidance on the labelling of manufactured nanoparticles and products containing manufactured nanoparticles* [16] (Entire Document)
- Stanford University *General Principles and Practices for Working Safely with Engineered Nanomaterials* [7] (Page 4)

2.9.3.1 Products to Label:

- British Standards Institute *Guidance on the labelling of manufactured nanoparticles and products containing manufactured nanoparticles* [16] (Page 5)

2.9.3.2 Label Information:

- British Standards Institute *Guidance on the labelling of manufactured nanoparticles and products containing manufactured nanoparticles* [16] (Pages 6-12)

3. Economic Evaluation

Economic Implications of Implementation			
Equipment	Specification	Range of cost (\$)	Reference
Size Selective Static Sampler	CASELLA Microdust Pro real time aerosol monitor kit	3956-5070	http://www.megadepot.com/product/view/product/asella-176170d-dust-detective-enclosure-for-microdust-pro#176170D
TEOM (Tapered Element Oscillating Microbalance)	1405-F TEOM, Continuous Ambient Air Monitor	\$26000/piece	http://www.thermoscientific.com/wps/portal/ts/products/detail?productId=11960554&groupType=PRODUCTION&searchType=0
ELPI (TM) (Electrical Low Pressure Impactor)	Electrical Low Pressure ELPI™ (Dekati Ltd.)	\$80000/piece	http://www.particleinstruments.com/products_measurement_aerosolsize.html
NanoRanger™ DMA (NanoEngineering Corporation)	NanoRanger™ DMA (NanoEngineering Corporation)	\$50000/piece	http://www.particleinstruments.com/products_measurement_aerosolsize.html
MOUDI (Micro-Orifice Uniform Deposit Impactor)	125-NR NanoMOUDI-II	\$30000/piece	http://www.appliedphysicsusa.com/nanoMOUDI_cascade_impactors.html
DMAS (Differential Mobility Analyzing System)	TSI Electrostatic Classifiers (3080 Series)	See SMPC below	http://www.tsi.com/en-1033/models/2206/3080_series.aspx
CPC (Condensation Particle Counter)	CONDENSATION PARTICLE COUNTER	\$30,000	http://www.tsi.com/en-1033/products/13992/condensation_particle_counter.aspx
OPC (Optical Particle Counter)	OPTICAL PARTICLE SIZER	\$12000 (normally buy 4-10 of these in different in different size range classes)	http://tsi.com/en-1033/products/4294967578/Optical%20Particle%20Sizer%20Model%203330.aspx?gclid=CITW6G0okcCFOQ-bAodOyFkdA
SMPS (Scanning Mobility Particle Sizer)	TSI Scanning Mobility Particle Sizer™ (SMPS™) spectrometer (Includes a suite of DMAS and Diffusion charger)	\$100,000-\$170,000	http://www.tsi.com/uploadedFiles/Product_Information/Literature/Application_Notes/SMPS-002appnote.pdf
Diffusion Charger	Aerosol mobility spectrometry based on diffusion charging	\$1,000	http://www.tsi.com/uploadedFiles/Product_Information/Literature/Posters/UFIPOINNET_EAC07_Hillemann_lecture.pdf
TEM (Transmission Electron Microscope)	LIBRA® 200 FE TEM	\$1.5 - 2 million	http://www.zeiss.com/us/nts
SEM (Scanning Electron Microscope)	EVO® MA 10 SEM	\$100,000 - \$200,000	http://www.zeiss.com/us/nts
Particle Analyzer	Nanotracs Particle Size Analyzer	\$34,000	http://www.microtrac.com/ProductsTechnology/NanotracsParticleSizeAnalyzer.aspx
LEV (Local Exhaust Ventilation)			
GEV (General Exhaust Ventilation)			http://www.chinaqualitylighting.com/wholesaler-hvac_exhaust/
Glove Box	Labconco® PRECISE™ Basic and HEPA-Filtered Glove Boxes	6,265/piece	http://www.coleparmer.com/catalog/product_view.asp?sku=3476300&px="
Glove Bag	Glove Bag™ Inflatable Glove Chambers	295/6 pack	http://www.coleparmer.com/catalog/product_view.asp?sku=0440834&px="
Biological Safety Cabinet Class I	Class I and HEPA Filtered Enclosures	\$5,500	http://www.labconco.com/_scripts/editc25.asp?catid=16
Biological Safety Cabinet Class II	Purifier® Logic® Class II Type A2 Biological Safety Cabinet, 3'W Hood, Fluorescent Light, UV Lights	8,745-10,500/piece	http://www.labsafety.com/Purifier-Logic-Class-II-Type-A2-Biological-Safety-Cabinet-3W-Hood-Fluorescent-Light-UV-Lights_s_155204Ductless-Fume-Hoods-and-Access_28351448/?cl_src=14110944&cl_sku=155204&CID=9PP001 http://www.labcompare.com/General-Laboratory-Equipment/69-Biological-Safety-Cabinet-Biosafety-Cabinet/
Biological Safety Cabinet Class III	Airstream® Class III Biological Safety Cabinet	\$54,000	http://www.bakerco.com/products/class-iii-biosafety-cabinets.html
Snorkel Hood	6'X1500MM EXHAUST VENT SNORKEL	969/piece	http://www.fishersci.com/wps/portal/ITEMDETAIL?itemdetail=%27item%27&productId=11775705&catalogId=29102&matchedCatNo=NC9980636&catCode=SA_SC&endecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15&keepSessionSearchOutPut=true&fromSearch=Y&searchKey=snorkel&highlightProductsItemsFlag=Y
Powder Handling Enclosure	Labconco* XPert* Bulk Powder Enclosures	14,776.30-26,093.35/piece	http://www.fishersci.com/ecomm/servelet/productdetail?storeId=10652&productId=9867174&catalogId=29102&matchedCatNo=10265165 10304163 103061 10265161 10265164 10265156 10304165 10210265160&endecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15&fromSearch=1&searchKey=Handling Powder Enclosure&highlightProductsItemsFlag=Y

Engineering Controls

Equipment	Specification	Range of cost (\$)	Reference
Ghost Wipes	Ghost Wipe Lead Dust Wipe	\$40.50/200	http://www.emssales.net/store/cart.php?m=product_detail&p=620
HEPA Vacuum	HEPA Vacuum	769-1,720/piece	http://www.industrialvac.com/category_s/5.htm?gclid=CM2arv_JoqcCFQVsgwodthwmCg
Smoke Detectors	First Alert Smoke Alarm	6-16/piece	http://www.google.com/search?q=smoke+detector&ie=utf-8&oe=utf-8&aq=&rls=org.mozilla:en-US:official&client=firefox-a#q=smoke+detector&hl=en&client=firefox-a&hs=2mW&rls=org.mozilla:en-US:official&prmd=lvnsb&source=univ&tbs=shop:1&tbo=u&sa=X&ei=IB1sTKmloX2tgObjP3EAg&ved=0CHwOrQQ&biw=1280&bih=557&bav=on.1.or.&fp=ca3424583e0d5426
Fire Extinguisher (Various Types, p 23)	First Alert Fire Extinguisher	15-59/piece	http://www.google.com/search?q=fire+extinguisher&ie=utf-8&oe=utf-8&aq=&rls=org.mozilla:en-US:official&client=firefox-a#q=fire+extinguisher&hl=en&client=firefox-a&hs=ZqW&sa=X&rls=org.mozilla:en-US:official&tbs=shop:1.brand:first+alert&prmd=lvnsu&ei=x1sTZCwLor6swOAieWmBA&ved=OCLMBEMEJKAMwEQ&biw=1280&bih=557&bav=on.1.or.&fp=ca3424583e0d5426
Barricade Tape	DO NOT ENTER Barricade Tape	\$4.99/roll	http://www.saraglove.com/Safety-Barricade-Tape-s/69.htm?gclid=CP6l89-p16YCFRBNqwodnW0SGw
Absorbent/Adsorbent/Surfactant Material	SPC* BattleMat* Camouflage Perforated Sorbent Roll	156.15/roll	http://www.fishersci.com/ecommerce/servelet/fsproduct_detail?storeId=10652&productId=768438&catalogId=29102&matchedCatNo=198194&endecaSearchQuery=%23store%3DSafety%23N%3D4294877816%23top%3DSafety_Spill+Control%23pp%3D15&fromSearch=1&searchKey=walk off Mat&highlightProductsItemsFlag=Y
Wipes	Contec* Polynit Heatseal P.A.T Wipes	101.04/pack of 150	http://www.fishersci.com/ecommerce/servelet/fsproduct_detail?storeId=10652&productId=1175534&catalogId=29102&matchedCatNo=19170931 19170934 191932 19170930 19170933&endecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15&fromSearch=1&searchKey=wipe Wipes&highlightProductsItemsFlag=Y
Tacky Mat	Purus* Cleanroom Tacky Mats	200-340/case of 8	http://www.fishersci.com/ecommerce/servelet/fsproduct_detail?storeId=10652&productId=677045&catalogId=29102&matchedCatNo=19125802 19125814 191817 19125839 19125830 19125823 19125811 1919125805 19125833 19125808 19125836 191258ndecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15&fromSearch=1&searchKey=mats Tacky Mat&highlightProductsItemsFlag=Y
Walk-Off Mat	Fisherbrand* Hard Surface Adhesive Mats	135-286/case of 4	http://www.fishersci.com/ecommerce/servelet/fsproduct_detail?storeId=10652&productId=5002115&catalogId=29102&matchedCatNo=19181518 19181520 191819181517 19181516&endecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15&fromSearch=1&searchKey=mats Tacky Mat&highlightProductsItemsFlag=Y
Fisherbrand Absorbent Surface Liner	Fisherbrand* Absorbent Surface Liners	264.19/case of 4	http://www.fishersci.com/ecommerce/servelet/fsproduct_detail?storeId=10652&productId=743547&catalogId=29102&matchedCatNo=1412746 1412747&endecaSearchQuery=%23store%3DSafety%23N%3D0%23pp%3D15&fromSearch=1&searchKey=Surface Liner absorbents surfaces Absorbent liners&highlightProductsItemsFlag=Y

Administrative Controls

Equipment	Specification	Range of cost (\$)	Reference
Disposable Filtering Facepiece	SELTS 3M N95 and P95 Filtering Facepiece Respirators; No Face Seal (NIOSH-approved)	1-5/piece	http://www.fishersci.com/wps/portal/SEARCHRESULTS?keyword=SELTS+3M+N95+and+P95+Filtering+Facepiece+Respirators&restrictedCategoryId=N-0&Nik=all&rp=&supCatNoOnOff=&imagesOnOff=&highlightOnOff=&teaserOnOff=&store=Scientific&type=&showAdvanceOptions=
Elastomeric Half-Facepiece	3M(tm) Small Thermoplastic Elastomer 6000 Series Half Facepiece Air Purifying Respirator With Two 3M(tm) 2091 P100 Particulate Filters	20-30/piece	http://www.prosafetysupplies.com/product/3M6191/3Mtm-Small-Thermoplastic-Elastomer-6000-Series-Half-Facepiece-Air-Purifying-Respirator-With-Two-3Mtm-2091-P100-Particulate-Filters.html?meta=GBASE&metaCpg=3M6191&utm_source=gbase&utm_medium=CPC&utm_content=&utm_campaign=3M6191
Elastomeric Full-Facepiece	North Safety 54001 Series Full Facepiece	107-350/piece	http://www.google.com/search?q=Elastomeric+Full-Facepiece&ie=utf-8&oe=utf-8&q=&rls=org.mozilla:en-US:official&client=firefox-a#q=Elastomeric+Full-Facepiece&hl=en&client=firefox-a&hs=RAD&rls=org.mozilla:en-US:official&prmd=lvns&source=lnms&tbs=shop:1&ei=NOY8Ta23L0e4sAPOx5TGAw&sa=X&oi=mode_link&cl=mode&cd=5&ved=0CBIO_AUoBA&blw=1280&bih=557&fp=241062ed1d424d73
N-100 Filter (Respirator)	3M OH&ESD 3M OHESD 142-8233 N100 Maint. Free Particulate Respirator; 3M N100 Respirator - Model MMM 8233	8-243/piece	http://www.google.com/#client=psy&hl=en&blw=1003&bih=595&tbs=shop:1&q=3M+Particulate+Respirator%2C+N100&aq=&aqi=&aqj=&aqk=&aqm=&aqn=&aqo=&aqp=&aqr=&aqst=&aqv=&aqw=&aqz=&fp=206d9629e0b4f1c
R-95 Filter	R95 Particulate respirator	2-140/piece	http://www.google.com/#client=psy&hl=en&blw=1003&bih=595&tbs=shop:1&q=Particulate+Respirator%2C+R95&aq=&aqi=&aqj=&aqk=&aqm=&aqn=&aqo=&aqp=&aqr=&aqst=&aqv=&aqw=&aqz=&fp=206d9629e0b4f1c
P-100 Filter	3M Respirator Filters P100	14/pair	http://www.professionalequipment.com/3m-respirator-filters-p100-1-pair-2097/asbestos-testing/?source=pegs&cid=PESEFGL
Nitrile Gloves	Disposable 4 mil Nitrile Exam Gloves Powder Free	\$5/box of 100	http://www.saraglove.com/Disposable-Powder-Free-Nitrile-Gloves-p/85-6185-p.htm
Latex Gloves	Disposable Latex Gloves Powder Free	\$4.29/box of 100	http://www.saraglove.com/Disposable-Latex-Gloves-Powder-Free-p/85-6135.htm
N95 Respirator	MCR NIOSH N95 Approved Particulate Respirator Mask T1200-70-14	13/20 pack	http://bostonindustrial.net/MCR-NIOSH-N95-Approved-Particulate-Respirator/MB001QCXVCA.htm
Anti-Static Shoes	Polyethylene Shoe Covers Blue, Anti Static, Impervious, Non linting	70-73/200 pair	http://www.tasco-safety.com/clothing/Sunsoft-impervious-boot-covers.html#t1200-70-14?ezppc=froogle
Tyvek by DuPont	DuPont Disposable Elastic Wrist, Ankle & Hood White Tyvek	4.99-196.25/piece	http://www.google.com/search?q=tyvek&ie=utf-8&oe=utf-8&q=&rls=org.mozilla:en-US:official&client=firefox-a#q=tyvek+coveralls&hl=en&client=firefox-a&rls=org.mozilla:en-US:official&prmd=lvns&source=univ&tbs=shop:1&bo=u&sa=X&ei=lo51TeqFCIz6sAPQodl6BQ&sq=2&ved=0CEkQrOQ&blw=1280&bih=557&bav=1,or,&fp=ca3424583e0d5426
Over the Shoe Booties	DSC Haz Mat Booties	11.90/pair	http://www.fishersci.com/ecomm/servelet/productDetail?storeId=10652&productId=766959&catalogId=29102&matchedCatNo=19049315 19049317 190547 19049316 19059621&endecaSearchQuery=%23ore%3DSafety%23N%3D0%23rpp%3D15&fromSearch=1&searchKey=the shoes Booties Over bootie Shoe sho&highlightProductsItemsFlag=Y
Nitrile Gloves with Extended Sleeves	Fisherbrand* Extended Cuff Nitrile Exam Gloves	25.60/pack of 50	http://www.fishersci.com/ecomm/servelet/productDetail?storeId=10652&productId=10208039&catalogId=29102&matchedCatNo=19041170A 19041170D 19041170B 19041170C&endecaSearchQuery=%23store%3DSafety%23N%3D0%23rpp%3D15&fromSearch=1&searchKey=Sleeves Nitrile Extended with Gloves&highlightProductsItemsFlag=Y
Gauntlet-Type Gloves	Ansell* Snorkel* PVC-Nitrile Blend Coated Gauntlets	93.03-105.69/dozen	http://www.fishersci.com/ecomm/servelet/productDetail?storeId=10652&productId=619665&catalogId=29102&matchedCatNo=19014903 19014914 190146 19014907 19014904 19120395 19014914&endecaSearchQuery=%23store%3DSafety%23N%3D0%23rpp%3D15%23Nao%3D0&fromSearch=1&searchKey=Gauntlet nit glove hand%20protection gauntlets Gloves&highlightProductsItemsFlag=Y
Safety Glasses	3M* Lexa* Safety Eyewear	640.86/100 pieces	http://www.fishersci.com/ecomm/servelet/productDetail?storeId=10652&productId=814272&catalogId=29102&matchedCatNo=19034443 191500144 190339B 19145415 191501323 190334395 1915001434824 19807979 19034441 19034444 19807980 17982 191500142 19807981 190334405 19150132decaSearchQuery=%23store%3DSafety%23N%3D0294876159%23top%3DSafety_Eye+Protection+Products%23rpp%3D15&fromSearch=1&searchKey=glasses safety&highlightProductsItemsFlag=Y
Chemical Splash Goggles	Uvex* Futura* Chemical-Splash Goggles	15.60/piece	http://www.fishersci.com/ecomm/servelet/productDetail?storeId=10652&productId=817449&catalogId=29102&matchedCatNo=17987527&endecaSearchQuery=%23store%3DSafety%23N%3D0%23rpp%3D15&fromSearch=1&searchKey=goggles chemical spl&highlightProductsItemsFlag=Y

Personal Protective Equipment

3.1 Estimation of Construction Costs for Control Systems and other EH&S infrastructure:

Construction costs for any buildings or infrastructure vary greatly from any given facility handling ENMs. Costs can vary geographically and/or over time for any given amount/type of labor, materials and equipment. Information on construction costs is necessary to implement many EH&S guidance practices described in this guide such as HVAC system recommendations and other important infrastructure.

Fortunately there are industry standards for estimating construction costs that utilize existing data from thousands of construction jobs completed. This data is updated annually and includes descriptive statistics such as productivity rates for each construction project. Lists of vendors are also given with this data specific to each location.

There are several companies that provide this construction data and relevant services for the purposes of cost estimation. Examples of these firms are listed below:

Sweets Construction Cost Estimating Data [37]:

Product/Service Description:

“Labor, materials, and equipment prices have been calculated from the average cost of actual jobs completed in thousands of locations nationwide and presented in CSI MasterFormat -- the industry standard for estimating.

With this valuable resource, you'll be able to calculate overhead, profit, and productivity rates. A handy geographic conversion table is included so making adjustments for local costs is a snap.

Provides contractors, architects, engineers, and all other business professionals the highest available level of precision in predicting construction costs for: sitework, concrete and masonry, woods and plastics, thermal and moisture protection, doors and windows, finishes, specialties, equipment, furnishings, special construction, conveying systems, mechanical systems, and electrical systems.”[37]

RS Means, Reed Construction Data [38]:

Product/Service Description:

“RSMeans is North America's leading supplier of construction cost information. A product line of Reed Construction Data, RSMeans provides accurate and up-to-date cost information that helps owners, developers, architects, engineers, contractors and others to carefully and precisely project and control the cost of both new building construction and renovation projects.

In addition to its collection of annual construction cost data books, RSMeans also offers construction estimating and facilities management seminars, electronic cost databases and software, reference books, and consulting services.”[38]

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