Course Schedule

DAY ONE		
12:30-1:00		Check-in and pre-assessment
1:00-2:00	Module 1	Introduction to Nanotechnology and Nanomaterials
2:00-2:45	Module 2	What Workers Need to Know about Nanomaterial Toxicology
2:45-3:00		Break
3:00-4:00	Module 3	Assessing Exposure to Nanomaterials in the Workplace
4:00-5:00	Module 4	Controlling Exposure to Nanomaterials
5:00		End of Day 1
DAY TWO		
8:30-9:30	Module 5	Risk Management Approaches for Nanomaterial Workplaces
9:30-10:30	Module 6	Regulations and Standards Relevant to Nanomaterial Workplaces
10:30-10:45		Break
10:45-11:30	Module 7	Tools and Resources for Further Study
11:30-12:00		Course Wrap-Up

This material was produced under grant number SH-21008-10-60-F-48 from the Occupational Safety and Health Administration, U.S. Department of Labor. It does not necessarily reflect the views or policies of the U.S. Department of Labor, nor does mention of trade names, commercial products, or organizations imply endorsement by the U.S. Government.

Instructors

Kristen M. Kulinowski, PhD
kk@rice.edu

Dr. Kulinowski is an internationally recognized expert with over 10 years of experience in understanding and communicating the potential environmental, health and safety implications of nanomaterials. She holds appointments as Senior Faculty Fellow in the department of Chemistry at Rice University in Houston, Texas, Executive Director for Policy for the Center for Biological and Environmental Nanotechnology (CBEN) and Director of the International Council on Nanotechnology (ICON). As ICON director, Dr. Kulinowski directed efforts that resulted in the web publication of the first publicly available database of citations to peer-reviewed papers on nano-EHS, a survey of best practices for nanomaterial handling in the workplace, a public information portal on nano-EHS and the GoodNanoGuide, an interactive forum for sharing information about nanomaterial handling practices. She is co-author of a white paper on training hazardous waste workers to handle nanomaterials for the National Institute for Environmental Health Sciences and is principal investigator on a Susan Harwood Targeted Topics training grant from the Occupational Safety and Health Administration to develop instructional materials to assist small-to-medium sized nanomaterial companies in creating and sustaining safer workplaces. Dr. Kulinowski received a B.S. in chemistry from Canisius College and M.S. and Ph.D. in chemistry from the University of Rochester.

Bruce Lippy, PhD, CIH, CSP
bruce@thelippygroup.com

Bruce Lippy, PhD, is a certified industrial hygienist and a certified safety professional. He is President of The Lippy Group, LLC, which develops and delivers innovative HAZWOPER refresher courses, provides industrial hygiene programmatic support to the federal government, international unions and national construction firms and performs training program evaluations. He is an expert in communicating the hazards of operating and maintaining innovative environmental technologies and has served as Director of the National Clearinghouse for Worker Safety and Health Training. He served on a team that evaluated the hazards faced by emergency responders at the World Trade Center site in 2001, and was awarded the EPA's Bronze Medal for meritorious service on the EPA/Labor Superfund Task Force in June, 2004. Dr. Lippy is co-author of a guidance document on training hazardous waste workers to handle nanomaterials for the National Institute for Environmental Health Sciences and co-content developer of the OSHA Susan Harwood Targeted Topics Training program on nanomaterials and occupational health. Dr. Lippy also co-authored with Dr. Kulinowski a chapter on nanotechnology in *The Occupational Environment – Its Evaluation, Control, and Management, 3rd Edition.* Dr. Lippy received a B.A. in biology from Western Maryland College and a PhD in policy from the University of Maryland.

Course and Instructor Evaluation

Course: Intro to Nano and Occupational Safety	Instructors: Kristen M. Kulinowski and Bruce Lippy	
Training Location:		Date:
Student Name (optional):		

Please complete the following details so that we can continue to offer the best service possible. Pass them to your instructor at the end of the course.

In your view, what were the three most important strengths of the program?

In your view, what were the three most important weaknesses of the program?

	Poor	Fair	Good	Excellent
Course overall:				
How easy was the course to understand?				
Was the content suited to your requirements?				
Were the topics covered in sufficient detail?				
Would you recommend this course to others?				
Overall rating of the course				
Course Materials:				
Were the materials, handouts and activities useful?				
How well did the course materials follow the course?				
Overall quality of training materials?				

	Poor	Fair	Good	Excellent
Instructors:				
Ability to provide real world experience?				
Ability to respond appropriately to questions?				
How well prepared were the instructors?				
Knowledge of subject matter?				
Presentation abilities?				
Overall rating of instructors?				

Nano Safety Certification Program

After the training that you received, would you consider being certified ___Yes ___No

Would a certification be valuable to you and the company ___Yes ___No

Being certified in nano safety is important to the field

__strongly agree __agree __neutral __disagree __strongly disagree

Demographic Information

Gender: Male _____ Female _____

Job Title: Industrial Hygiene _____ Occupational Medicine _____

Occupational Health Nursing _____ Occupational Safety _____

Epidemiology _____ Injury Prevention and Control _____

Environmental Health _____

Other (please specify) ____

Highest Level of Education:

High School _____ Some college _____ Associates Degree (2-yr) _____

BA or BS _____ MS/MA/MPH _____ Doctorate _____ Other ______

Module 1: Introduction to Nanotechnology and Nanomaterials

Lesson Overview

The purpose of this lesson is to provide workers with introductory information about nanotechnology and nanomaterials.

These topics will be covered:

1. How small is a nanometer?
2. Definitions and commonly used terms
3. How is the nanoscale different from the macroscale or the atomic scale?
4. Major classes of nanomaterials and their benefits

Learning Objectives

At the end of this module you will be able to

- Contrast objects at the nanoscale with larger and smaller forms of matter
- Define key terms in nanotechnology
- Explain some of the ways nanomaterial properties differ from molecules and microscale particles
- Describe some of the physical and chemical characteristics that can change at the nanoscale
- Describe some of the major classes of nanomaterials produced today and their properties and potential benefits

Topic 1: How small is a nanometer?

1 nm = 0.000000001 m

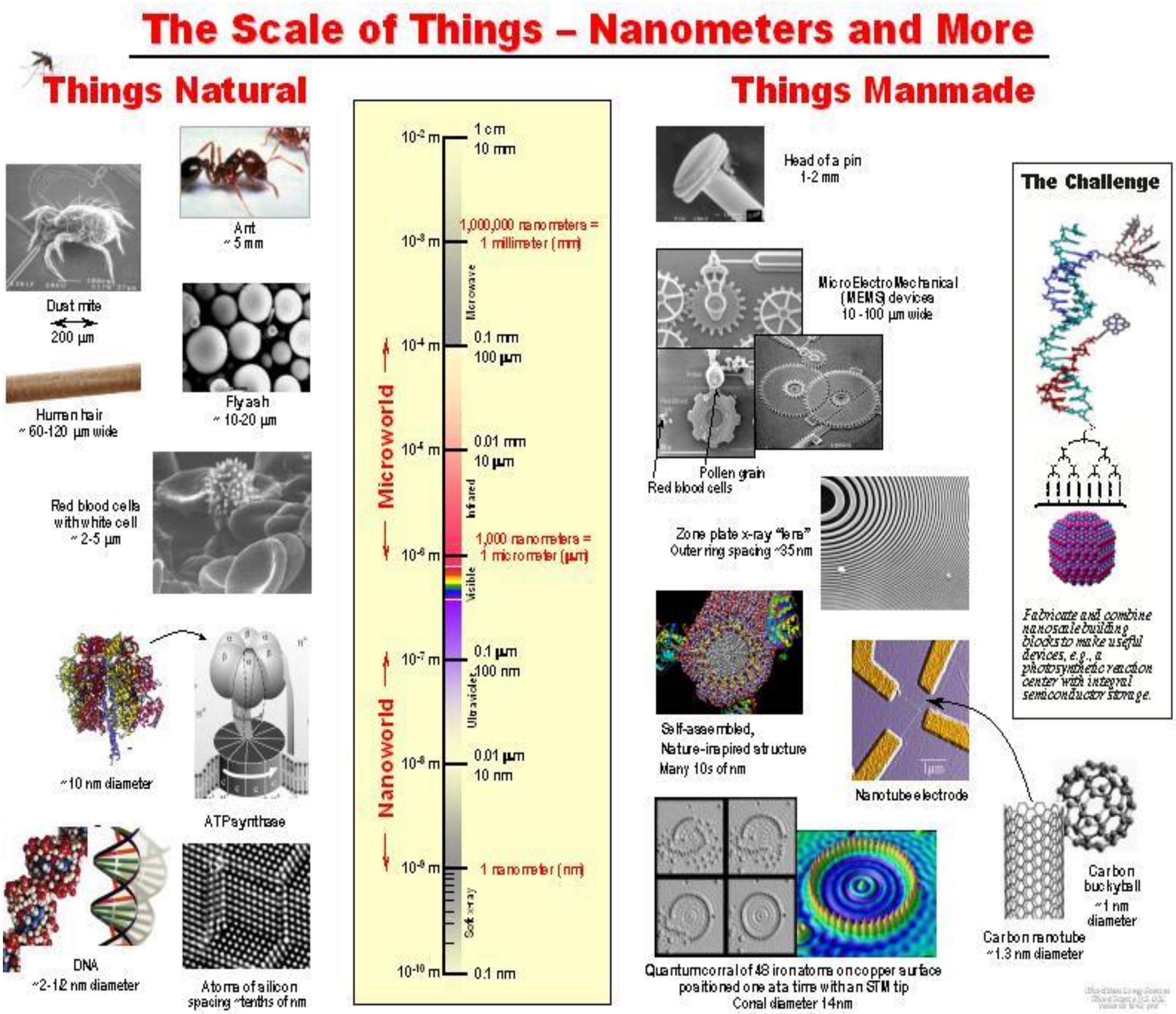
= 10^{-9} m

= one billionth meter

The size of any object worthy of the name “nanobug” cannot be estimated by squeezing together one’s fingers nor seen by squinting one’s eyes. The nanoscale is much too small for us to experience directly with our senses.

As with chemical substances, nanoscale objects may be present in the working environment with little to alert the worker of a possible exposure. Just because you can’t see it, feel it, smell it or taste it doesn’t mean it’s not there.

Handout 1



Remember that "nano" does not simply mean "very small". There are many forms of matter much smaller than a nanometer, including electrons, atoms and most molecules. The nanoscale is *in between* the very small atomic regime and the larger regime of microparticles and colloids.

On the left of the diagram are naturally occurring objects of various sizes. On the right are human-designed objects of various sizes.

There are plenty of natural objects that fall within the nanoscale, notably DNA and some larger proteins. Whether these can be called "nanotechnology" will be addressed in Topic 2.

Where does each of these fit?

Place the following objects on the ruler according to their approximate size. (Use diameter unless otherwise specified.)

1. Bacterium
2. Ant
3. Molecule
4. Buckyball (C_{60})
5. Virus
6. Human hair
7. Atom

1 m	1 dm	1 cm	1 mm	100 µm	10 µm	1 µm	100 nm	10 nm	1 nm	1 Å	0,1 Å
1 m	10^{-1} m	10^{-2} m	10^{-3} m	10^{-4} m	10^{-5} m	10^{-6} m	10^{-7} m	10^{-8} m	10^{-9} m	10^{-10} m	10^{-11} m

Topic 2: Definitions and Commonly Used Terms

Key terms include nanotechnology, nanoscale, nanomaterial, nanoparticle and nanofiber. There are several standard definitions for each of these.

GROUP ACTIVITY (See Handout 2)

In groups of 3-5, find similarities and differences among the definitions of nanotechnology, nanoparticle and nanomaterial published by ASTM, BSI and OSHA.

Handout 2

A Selection of Standard Definitions and Terms

Nanotechnology

ASTM International: E 2456 – 06

> nanotechnology, *n*—A term referring to a wide range of technologies that measure, manipulate, or incorporate materials and/or features with at least one dimension between approximately 1 and 100 nanometers (nm). Such applications exploit the properties, distinct from bulk/macroscopic systems, of nanoscale components.

British Standards Institute PAS 71: 2005

> design, characterization, production and application of structures, devices and systems by controlling shape and size at the ***nanoscale***
>
> > ***nanoscale****: having one or more dimensions of the order of 100 nm or less*

OSHA website

> Nanotechnology is the understanding, manipulation, and control of matter at dimensions of roughly 1 to 100 nanometers, which is near-atomic scale, to produce new materials, devices, and structures.

Nanoparticle

ASTM International: E 2456 – 06

> nanoparticle**,** *n—in nanotechnology*, a sub-classification of ***ultrafine particle*** with lengths in two or three dimensions greater than 0.001 micrometer (1 nanometer) and smaller than about 0.1 micrometer (100 nanometers) and which may or may not exhibit a size-related intensive property.
>
> > ***ultrafine particle****, n—in nanotechnology*, a particle ranging in size from approximately 0.1 micrometer (100 nanometers) to .001 micrometers (1 nanometer).
> >
> > DISCUSSION—The term is most often used to describe aerosol particles such as those found in welding fumes and combustion by-products…

British Standards Institute PAS 71: 2005

> particle with one or more dimensions at the ***nanoscale***

OSHA website

> No definition published

Nanomaterial

ASTM International: E 2456 – 06

> No standard definition published.

British Standards Institute PAS 71: 2005

> material with one or more external dimensions, or an internal structure, on the ***nanoscale***, which could exhibit novel characteristics compared to the same material without ***nanoscale*** features

OSHA website

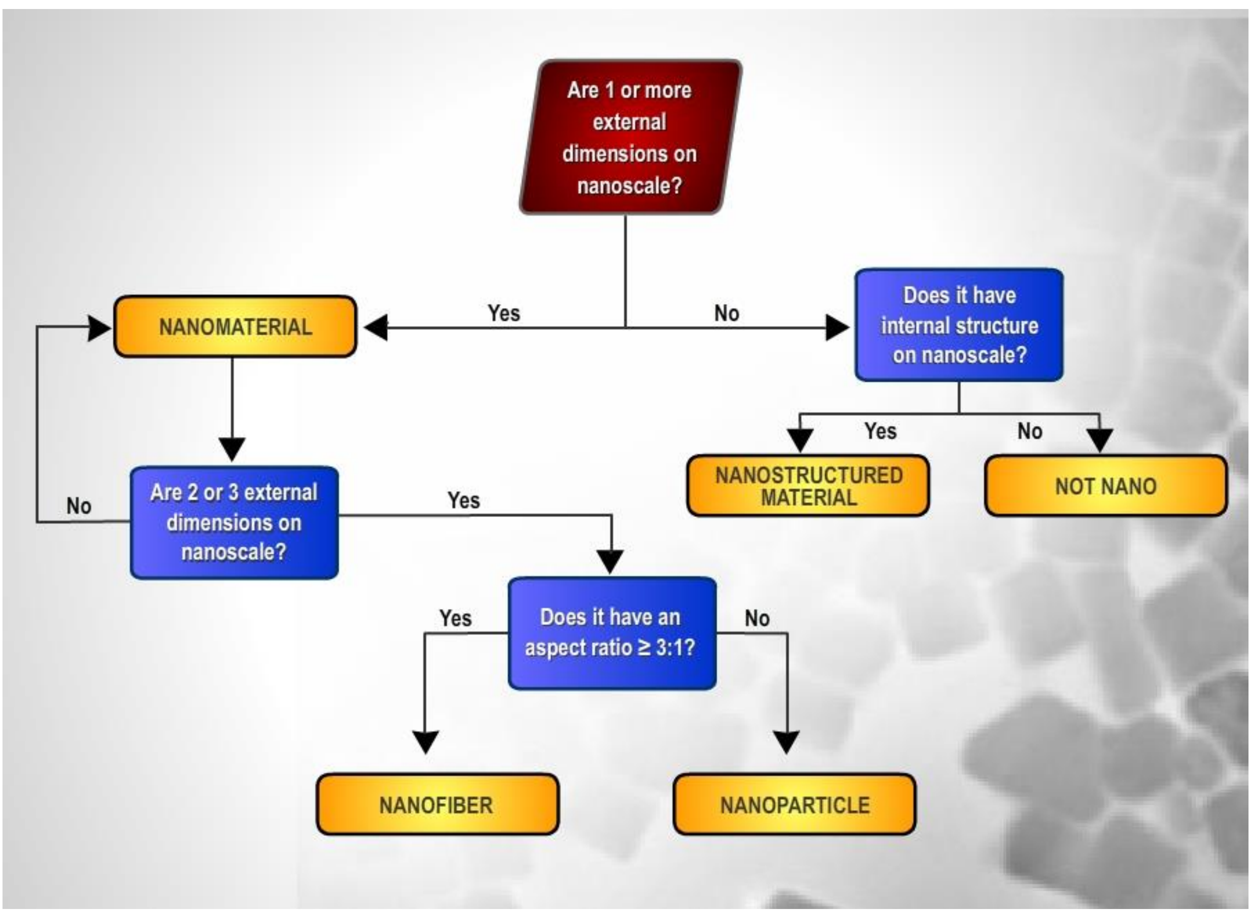
> **Engineered nanoscale materials or nanomaterials** are materials that have been purposefully manufactured, synthesized, or manipulated to have a size with at least one dimension in the range of approximately 1 to 100 nanometers and that exhibit unique properties determined by their size.

There are other standards produced by voluntary standard developing organizations, most notably ISO, but no consensus has emerged yet about which set of definitions will prevail. OSHA's definition of nanotechnology conforms more or less to that posted on the National Nanotechnology Initiative's nano.gov website.

Nanomaterial: Like its definition for nanoparticle, BSI's nanomaterial definition references one or more dimensions at the nanoscale. However, it distinguishes between *external dimensions* (meaning "of the whole object") and *internal structure*. Therefore an object can be larger than 100 nm in all three dimensions yet still be considered a nanomaterial if it has structural features within the nanoscale range. OSHA simply refers to one or more dimensions between 1-100 nm. Both BSI and OSHA refer to special properties but the BSI definition is less restrictive about this requirement ("could exhibit" for BSI vs. "that exhibit" for OSHA). ASTM does not define this term.

For the purposes of this course, we will use the OSHA definition of nanomaterial and the ASTM definition of nanoparticle.

Flowchart for Nanotechnology Terms

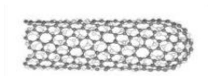


This flowchart uses the OSHA and BSI criteria for nanomaterial, the ASTM definition of nanoparticle and the BSI definition of nanofiber. Nanofibers and nanoparticles can be called nanomaterials. They differ only in their length-to-width aspect ratio. Long and narrow objects are more accurately described as nanofibers whereas objects that are more spherical than needle-like are better described as nanoparticles. To be safe, one can simply call an object with one or more external dimensions on the nanoscale a nanomaterial.

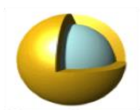
IMAGE CREDITS: Quantum dot tetrapod: Mike Wong, Rice University; Nanofiber: DOI: 10.1002/adma.200803174

What is it?

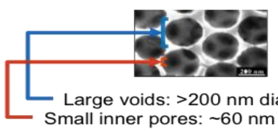
Use the flowchart to determine what each of these objects should be called.



1.5 nm x 1.5 nm x 10 μm



60 nm diameter
(57 nm core: 3 nm shell)



SOURCE: nanoshell is from nanospectra.com; macroporous nickel is from [Advanced Materials article]

Different Types of Nanomaterials

Naturally Occurring	Human Origin (Incidental)	Human Origin (Engineered)
Forest fires	Cooking smoke	Metals
Sea spray	Diesel exhaust	Quantum dots
Mineral composites	Welding fumes	Buckyballs/Nanotubes
Volcanic ash	Industrial effluents	Sunscreen pigments
Viruses	Sandblasting	Nanocapsules

Naturally occurring: There are many materials that satisfy the size requirements of the nanoscale but are produced naturally rather than in a factory or research lab. Combustion products (e.g., from a forest fire) and volcanic ash are both composed of a range of substances and particle sizes, some of which are on the nanoscale. Viruses could even be considered nanoscale particles.

Human Origin (incidental): Humans engage in many activities that produce nanoscale particles as an unintentional waste product of the process. Workers may be familiar with examples from welding, sandblasting or other industrial processes. Some of these particles have been implicated in unwanted public or occupational health outcomes.

Human Origin (Engineered): When we speak in this course about nanomaterials we will be talking about the third class shown in the table, the particles that have been intentionally designed to be in the nanoscale and are being studied or used commercially because of their novel properties. Some examples, about which more will be presented later, include nanoscale metals such as nanosilver, semiconducting nanoparticles known colloquially as quantum dots, carbon-based nanomaterials such as nanotubes, ceramic (metal oxide) nanoparticles such as titanium dioxide which is found in sunscreens, and polymeric hydrocarbon-based nanoparticles such as capsules used for drug delivery.

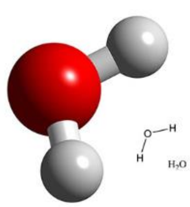
The main differences between Incidental and Engineered nanomaterials are that Engineered nanomaterials are intentionally designed to exploit a novel feature that accompanies the small size and are typically better controlled than randomly produced Incidental nanomaterials.

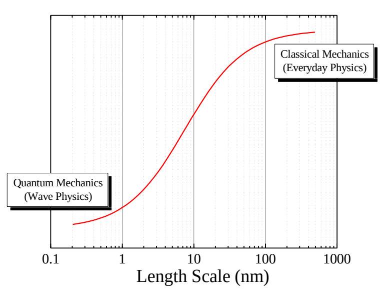
Topic 3: How is the nanoscale different from the macroscale or the atomic scale?

Baseball: ~2.8 inches in diameter

Softball: ~3.8 inches in diameter

Nanomaterial Properties Can Change with Size





The nanoworld

Very small forms of matter such as atoms and molecules have their own set of rules and don't behave the same way as larger objects.

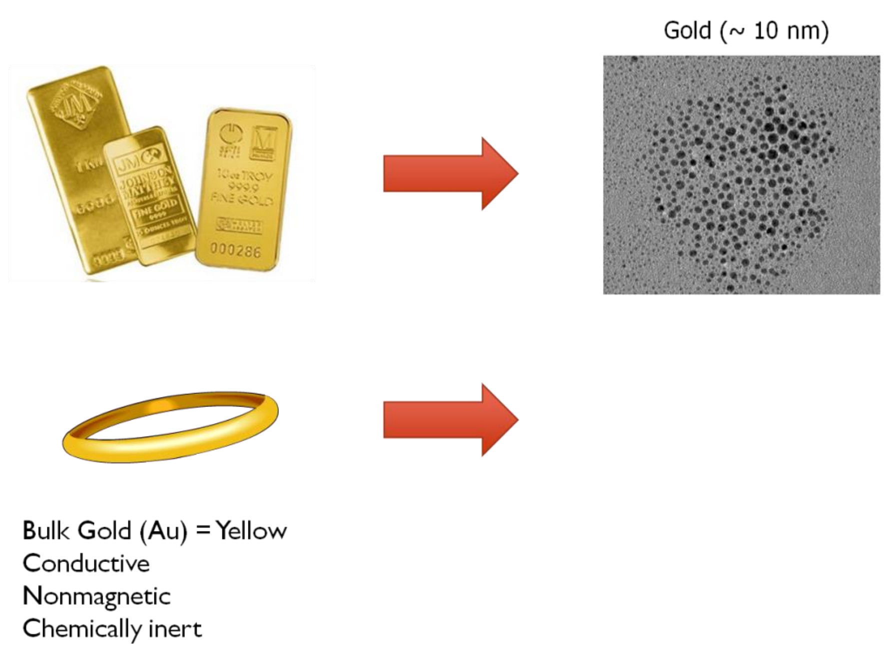
Start with an individual water molecule. We can't see or feel individual water molecules but when conditions are right the individual molecules start to cluster together into tiny droplets. The droplet may start off as a cluster of 5 or 6 molecules, at which point it's not much different than a single molecule. However, the bigger the cluster gets, the more it begins to resemble a raindrop. As more and more molecules cluster together, the droplet gets heavier and heavier until eventually it falls from the sky. In other words, there is a point at which the cluster of water molecules stops resembling an individual gas-phase molecule and starts resembling a liquid-phase raindrop. The water undergoes a smooth transition from gas to liquid simply as a result of its change in size.

This is an important concept for nanomaterials. The nanoscale world lies between the realms of molecules (such as H_2O) and larger objects we can perceive with our senses (such as a raindrop). A nanoparticle's properties can change with its size because it is transitioning from the atomic world to the macroscopic world. Unlike water, though, the changes some substances undergo as they transit through the nanoscale can include properties we wouldn't expect to change.

Early Nanotechnologists

While the term nanotechnology is new, artisans have been making and working with nanoparticles for millennia. The Lycurgus cup is a stunning example of dichroic ("two colors") glass from the late Roman period (4th century AD). The cup appears green in reflected light and red when lit from behind. Modern analysis revealed the glass contains 50-100 nm particles of a silver-gold alloy. The small size of these particles is responsible for the dichroic effect.

Would you buy *this* gold?



You cannot assume that you understand the behavior of a nanomaterial just because you understand the same material at the atomic/molecular or macroscopic levels.

Physical and Chemical Properties that can Change at the Nanoscale

Color

Melting temperature

Crystal structure

Chemical reactivity

Electrical conductivity

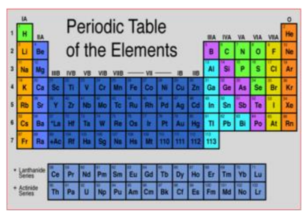
Magnetism

Mechanical strength

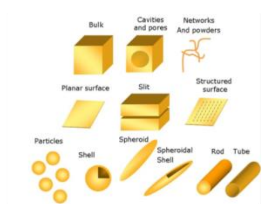
This is a partial list of some of the physical and chemical properties that can change for a given nanomaterial. Not all of these changes will be relevant for every nanoparticle; each will have its own set of variable properties.

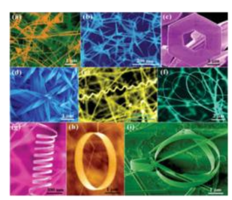
Nanomaterials Exhibit Diversity in…

Chemical composition

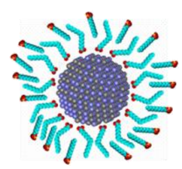


Form or shape





Surface treatments

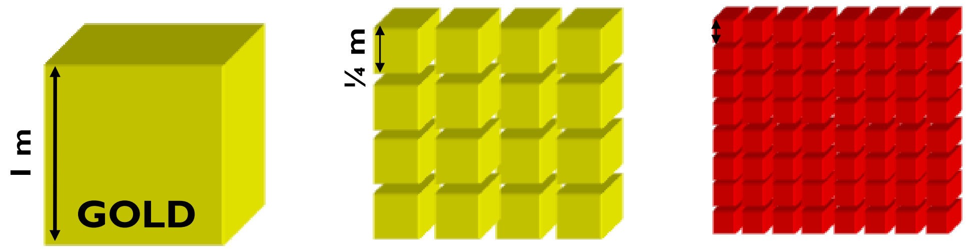


TOP: Novel materials can be made just by taking elements in the periodic table and combining them to form objects within the nanoscale range. There is incredible *chemical diversity* among nanomaterials.

MIDDLE: Note the wide variety of different shapes of the objects shown in the middle right image (and that the color was added to the microscope images for visual appeal). Each one of those objects has exactly the same chemical formula: ZnO. Nanoscientists and engineers can take the same substance and shape it into many different types of nanoscale objects. There is great *structural diversity* among nanomaterials.

BOTTOM: Manufacturers often change the surface of a nanoparticle during product formulation to achieve the desired dispersability, stability or activity. These surface modifications may impact the properties to such an extent that the surface-treated particle is, for all purposes, an entirely different substance than the non-treated particle.

Surface Area is a Big Factor



Each side = 1 m
Mass ≈ 43,000 lb
Surface Area (SA) = 6 m^2
≈ 8 ft x 8 ft room

Each side = 1/4 m
Mass ≈ 43,000 lb
SA = 24 m^2

Each side = 1 nm
Mass ≈ 43,000 lb

One reason why a nanomaterial is different than the larger form of the same substance is the increased surface area that results from dividing the larger material into many smaller pieces. Note how much more surface area a large block of gold has when it is divided up so that all the pieces are one nanometer in dimension. The mass and volume of the material is unchanged by the division of the block into small pieces.

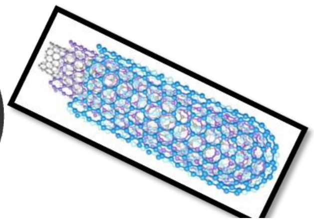
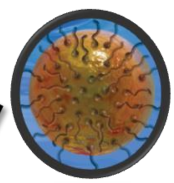
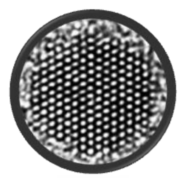
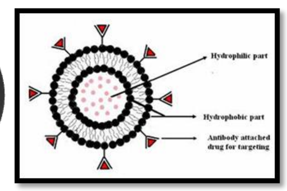
IMPLICATION FOR WORKERS: The gold atoms inside the big block are effectively hidden from whatever it is exposed to but cutting the block up into smaller pieces brings more of the gold atoms to the surface where they become available to react. Surface area and quantum mechanical effects account for many of the changes in chemical and physical properties observed at the nanoscale.

Topic 4: Major classes of nanomaterials and their benefits

Major Classes of Nanomaterials and Sample Applications

One way to categorize nanomaterials is by their chemical composition. Many of the most commercially important nanomaterials can be categorized into one of the five classes listed here.

Category	Chemical Composition	Product example
Fullerenes, Nanotubes; Nanowires	carbon, boron nitrides	Anti-static fabrics
Metals	silver, gold, iron, copper	Anti-microbial wound dressings
Ceramics (metal oxides)	titanium dioxide, zinc oxide, cerium oxide	Sunscreen filters, self-cleaning glass
Semiconductors (Quantum dots)	cadmium selenide, cadmium telluride	Medical imaging agents
Polymeric	hydrocarbon polymers	Drug delivery devices

Fullerenes, Nanotubes; Nanowires: Most materials in this class are made from carbon. These include the family of compounds derived from the C_{60} molecule known as buckminsterfullerene or buckyball, as well as the class of materials known as nanotubes. Nanotubes are simply elongated versions of the buckyball and can exist in single-walled, double-walled or multi-walled configurations.

Metals: There are many examples of nanometals in use today. The most commercially relevant is likely to be nanosilver, which is prized for its potent and broad-spectrum antimicrobial properties. Nanosilver is used in a number of consumer products ranging from spray disinfectants to toothpaste and teddy bears, as well as in many medical applications such as wound dressings and catheters. Nanosilver is even being researched for use in animal feed to reduce the need for conventional antibiotics

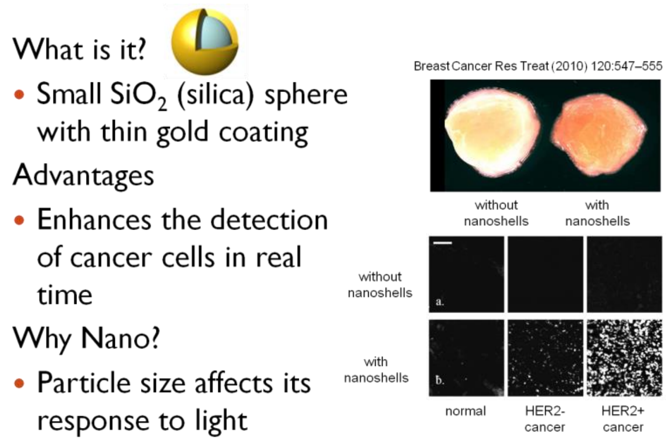
Ceramics: Another very broad class of materials that includes titanium dioxide, which is used in sunscreens and to coat so-called “self-cleaning glass”, as well as cerium oxide, which is a fuel additive that promotes greater fuel efficiency.

Semiconductors (Quantum Dots): These exhibit very bright photoluminescence and can be used as medical imaging agents. Unlike conventional dyes, quantum dots do not degrade quickly and have much brighter luminescence, thus enhancing the signal in a medical image. Their surfaces can be modified to direct them to specific cells in the body, including cancer cells, which can aid in disease detection.

Polymeric: Polymeric nanoparticles are small beads made from polymeric hydrocarbons. They can serve as containers for drug molecules and can be designed to deliver the drug to the precise location via surface modification with biomarkers that target a certain type of cell, for example. Polymeric nanoparticles are also used in the cosmetics industry to encapsulate active ingredients and potentially deliver them beneath the epidermis.

Detecting Cancer Cells

Nanoshells are nanoparticles with a core of silica (SiO_2, silicon dioxide, main component of glass) and a thin coating of gold. In this application the nanoshells have a molecule attached to the surface that causes it to bind to the surface of a particular type of breast cancer cell (HER2+). Once bound to the cancer cell the nanoshell's optical properties, which are a direct consequence of its nanoscopic size, enable the cancer cells to be more easily detected.



TOP: Application of targeted nanoshells creates a red hue in tumor tissue that can be visualized macroscopically with the eye.

BOTTOM: Nanoshells also cause the cancer cells to light up under a microscope (near-infrared reflectance confocal microscopy)

In either case this technology could permit the surgeon to assess whether all the cancerous tissue has been removed while the patient is still on the operating table rather than relying on post-operative assessment which could result in additional surgery.

Self-Cleaning Glass

In self-cleaning glass, a thin film of titanium dioxide (TiO_2 or titania) is bonded to glass. Upon exposure to UV from sunlight, the titania catalyzes breakdown of dirt. Rainwater then washes dirt away. The film also creates a hydrophobic surface which causes water to flow in sheets rather than beading up. As a result, little to no streaking occurs after water evaporates.

This coating can also be made to reflect UV light which can result in greater energy efficiency for the building due to reduced air-conditioning costs.

Small Change, Big Savings

What is it?

- Thin film of polymer bonded to paint

Advantages

- Reduces friction-causing debris build-up on plane surface
- Reduces fuel consumption 1-2% ➡ ~$22 million

Why Nano?

- Film adds a mere 4 oz to weight of the jet (compared to 176 pounds of paint)

Balancing the Benefits and Risks

Nanomaterials' special physical and chemical properties may lead to unexpected interactions with biological and environmental systems.

The novelty of certain nanomaterials may be a double-edged sword. Society supports the development of novel nanoscale materials because of their different physical and chemical properties. But this novelty could result in unwanted impacts on humans or the natural environment. As we're developing technologies to solve one problem we should ensure we are not contributing to another. There is a growing body of information about nanomaterial toxicity that must be considered in designing and implementing a safe workplace.

Module 2: What Workers Need to Know about Nanomaterial Toxicology

Lesson Overview

The purpose of this module is to provide workers with information on the environmental, health and safety impacts of nanomaterials and to give you an overview of the current understanding of nanomaterials' health and safety impacts with an emphasis on human health.

These topics will be covered:

1. Federal support for nanotechnology and nano- environmental, health and safety (EHS) impacts research
2. Tools for finding the most up-to-date information on nano-EHS impacts research
3. Significant findings from the nano EHS literature

Learning Objectives

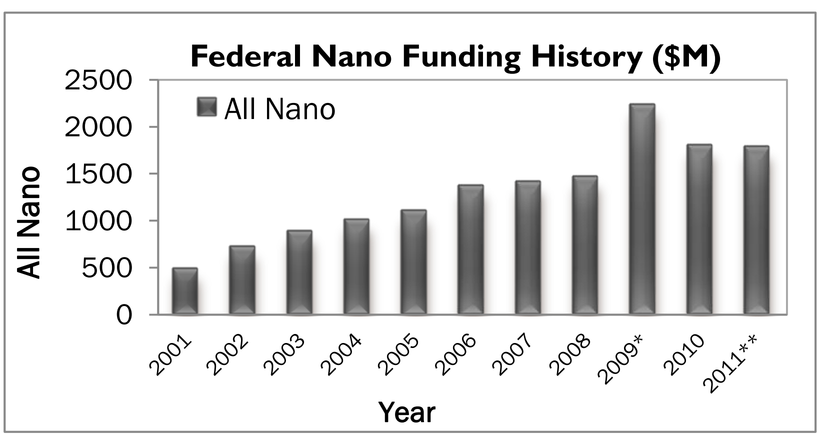
At the end of this module you will be able to

- Find the latest research on the environmental, health and safety (EHS) impacts of nanomaterials using freely available web resources
- Summarize some of the significant EHS research of the past few years
- Articulate the significance of the EHS research to occupational safety

Topic 1: Federal support for nanotechnology and nano-environmental, health and safety (EHS) impacts research.

Federal Investment in Nanotechnology Research

The National Nanotechnology Initiative (NNI) was created in 2001 under President Clinton to organize the loose federation of federal agencies that were then supporting research and development of nanotechnologies. Twenty-five different agencies are part of the NNI. Each of them has its own funding for nanotechnology R&D activities. The numbers on these graphs are the sums of all agencies' nanotechnology activities.

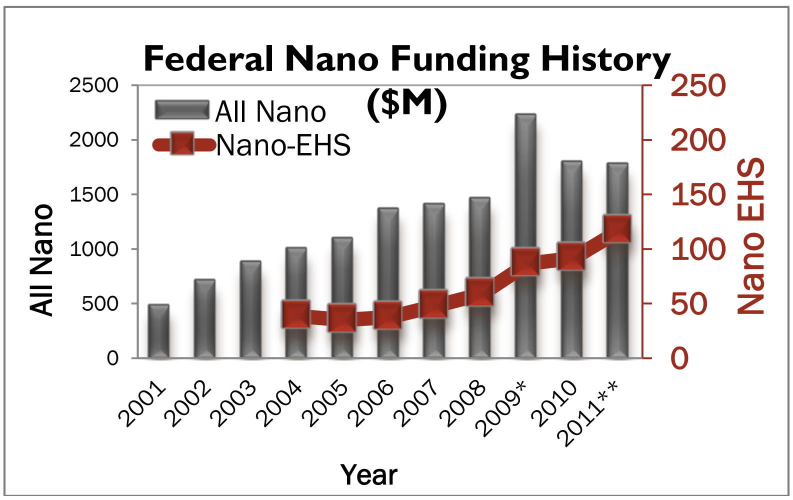


*The bump in 2009 funding is the result of additional funding from the American Reinvestment and Recovery Act ("stimulus").

** The 2011 numbers are proposed and won't be finalized until the agencies receive their formal budgets from Congress (due in October 2010)

Federal Investment in NanoEHS Research

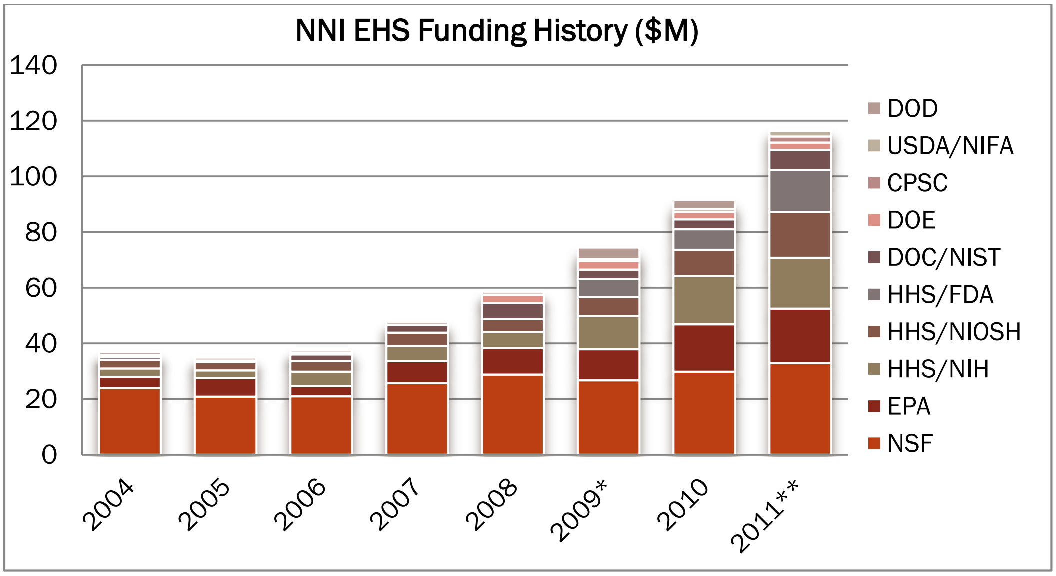
Here is the same graph showing total NNI funding since its inception in 2001. Superimposed on top of that are the portions of those dollars that went toward NanoEHS research. Note that the NanoEHS numbers correspond to the right-hand y axis which is 10 times smaller than the left-hand y axis. The bottom line is that NanoEHS research has made up between 3-7% of the total NNI budget.



NanoEHS numbers are not provided for the early years of the NNI before 2004 but probably did not exceed 4% of the total NNI budget. During this time, EHS research was funded but often combined for reporting purposes with educational and social science funding. Over 40% of federally sponsored nanoEHS research has been funded by the National Science Foundation (NSF) which greatly exceeds any other agency. Here are the rest:

- Environmental Protection Agency – 16%
- National Institutes of Health – 15%
- National Institute for Occupational Safety and Health – 10%
- Food and Drug Administration – 6%
- National Institute for Standards and Technology – 5%
- Department of Energy – 3%
- Consumer Product Safety Commission – 1%
- US Department of Agriculture/National Institute of Food and Agriculture – 1%
- Department of Defense – 2%

NanoEHS Funding by Federal Agency



OSHA does not fund nanoEHS research. Though the regulatory side of HHS/FDA had been active in nanotechnology issues for several years prior, FDA only began to fund NanoEHS research in 2009.

Topic 2: Tools for Finding the Most Up-to-date Information on NanoEHS Impacts Research

One-Stop Shop for NanoEHS Info

The International Council on Nanotechnology (ICON), a group based at Rice University in Houston, TX, maintains a comprehensive website on all aspects of nanomaterial environmental, health and safety impacts. Appearance on the ICON website does not endorse the material as authoritative, merely that it is relevant to the subject of NanoEHS.

http://icon.rice.edu

Virtual Journal of NanoEHS

An easy way to keep track of the current nano-EHS research is provided by the "Virtual Journal of NanoEHS," a repository of citations to research papers that study some aspect of NanoEHS impacts. This is called a virtual journal because it collects work published in other journals, filters it by topical relevance and organizes it into a searchable format. The database is updated weekly and contains thousands of citations. The VJ does not provide the papers themselves but posts the abstracts and links to the source journal where the papers can be obtained.

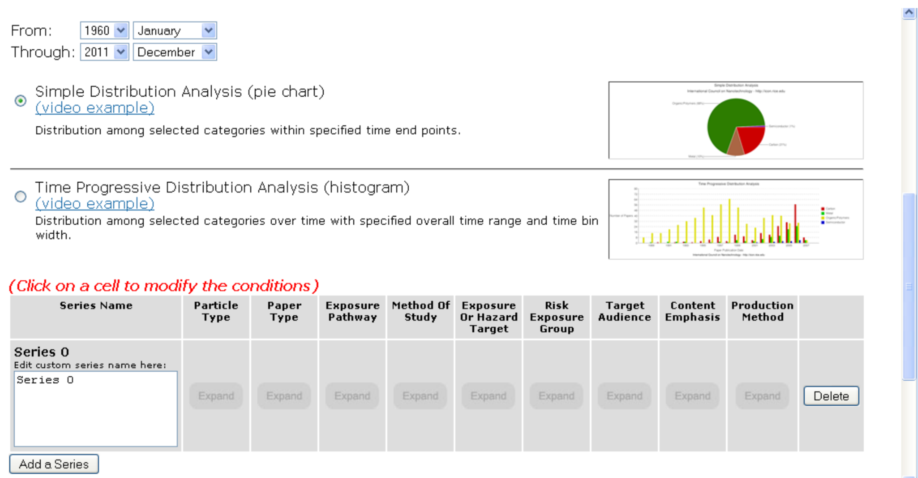
http://icon.rice.edu/virtualjournal.cfm

Do Your Own Analyses

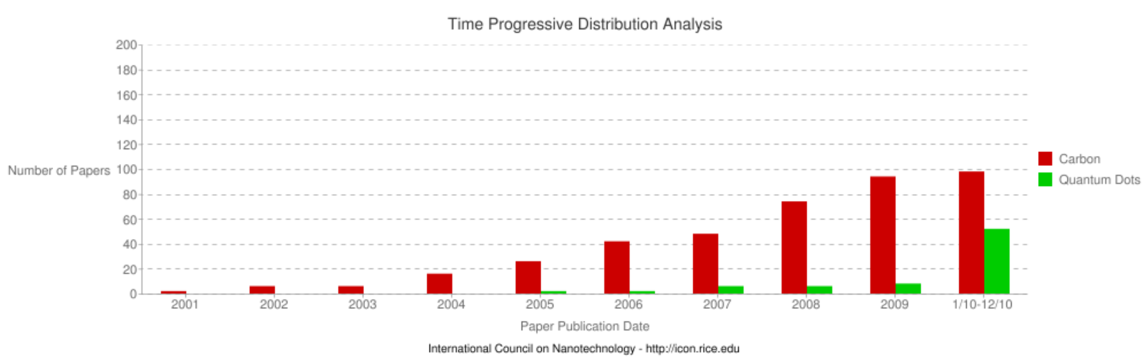
Each entry into the VJ is tagged according to 9 indices, including particle type, exposure pathway and risk exposure group. The Database Analysis Tool allows one to search and do comparative analyses of the database.

http://icon.rice.edu/report.cfm

Using the VJ database answer this question: *How many peer-reviewed publications in each year of the last decade addressed the hazards of carbon-based nanomaterials vs. semiconducting quantum dots?*

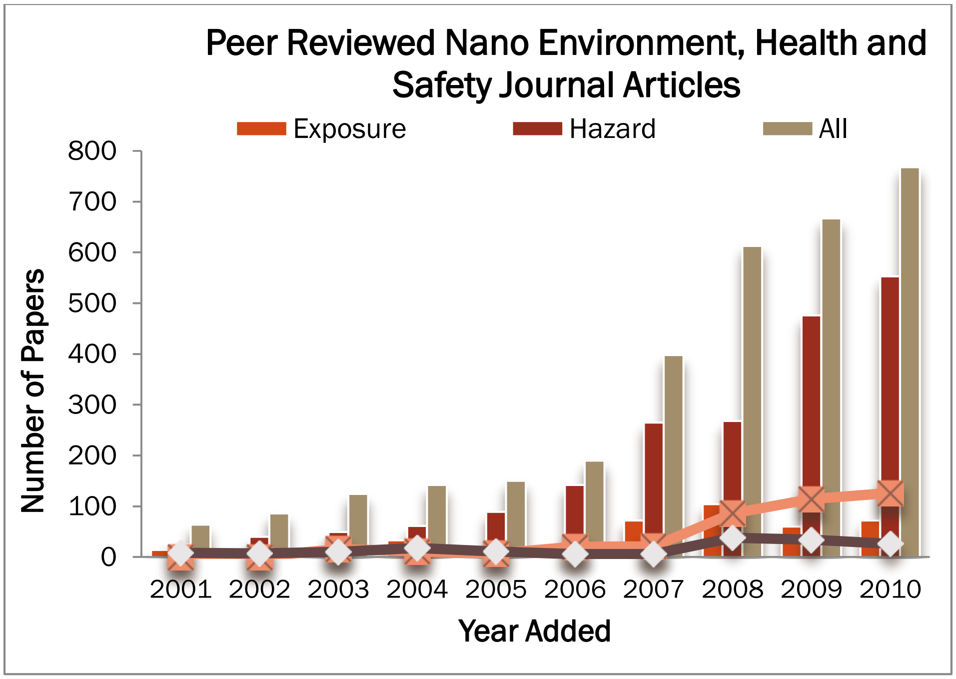


Search Results



What Does All This Research Tell Us?

Mining a literature database is not a substitute for detailed analysis of the knowledge base in an area; however, it can illuminate some trends that are real. For nanomaterials, several knowledge gaps in the published research correspond closely with gaps that researchers in the field have agreed are critical to fill. *These graphs were produced using the analysis tool.*



The first gap is one of hazard vs. exposure. Many papers in the database assess the toxicity of a particular nanomaterial in a laboratory setting. *Hazard* papers represent more than 60% of all the published nanomaterial risk research over the last decade. Many of these studies were done in cell culture. In contrast, a much more limited body of work has explored the potential for *exposure* to nanomaterials by documenting sources and releases, translocation within the body or an ecosystem, etc. *Just because a substance kills cells in a Petri dish doesn't mean it will cause harm to a worker.* The exposure research needs to catch up with the hazard research so a more complete assessment of risk can be made.

Two other gaps revealed by the database and supported by expert analysis are knowledge about the impacts of nanomaterials on the environment and research of direct relevance to occupational practice. In this analysis, environmental research comprises 13% of all papers published in the last decade and occupationally relevant research comes in at a mere 4%. Examples of occupationally relevant research are studies that measure nanomaterial flow in a fume hood, field studies of workplace exposure, tests of personal protective equipment against nanomaterials or efficacy of particle counters, etc.

So, while nearly 5000 papers seems like a lot, this knowledge base still has little practical application to human health.

Different Types of Nanomaterials

The focus of this course is on the human origin (engineered) nanoscale materials but when it comes to occupational health there is much we can learn from research on the health effects of incidentally produced nanoscale particles.

What do you know about the health effects of any of the items listed above?

Write your answers below.

Human Origin (Incidental)	Health Impacts
Cooking smoke	
Diesel exhaust	
Welding fumes	
Industrial emissions/effluents	
Sandblasting	

Topic 3: Significant findings from the NanoEHS literature

Inhalation has been a major focus of the nanotoxicology community; NP penetration into the lung depends on its aggregation state

- Airborne NPs can be inhaled and deposit in the respiratory tract
- Inhaled NPs may enter the blood stream and translocate to other organs

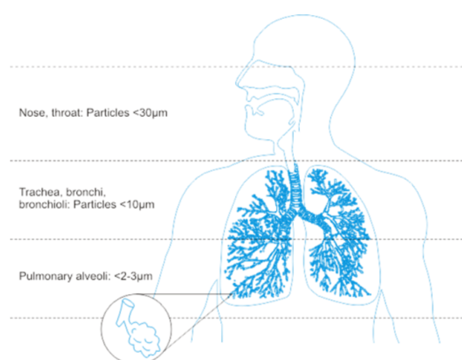


Image: http://upload.wikimedia.org/wikipedia/commons/3/36/Respiratory_Tract.png

Routes of Exposure: Inhalation

The ability of a particle to deposit in the respiratory tract depends on its size. Particles larger than about 10 microns (10,000 nm) get trapped by the mouth, nose and throat; only particles less than ~10 microns enter the conductive airways (trachea and bronchi). Many of these particles are trapped by mucus and ultimately ingested. Nanoparticles' small size permits them to be inhaled into the alveolar (deep) region of the lung where gas exchange occurs. For this reason, many studies and guidance documents have focused on inhalation as the primary route of exposure to nanoparticles in the workplace.

Animal studies have indicated that nanoparticles in the lung may be able to enter the bloodstream and translocate to other organs.

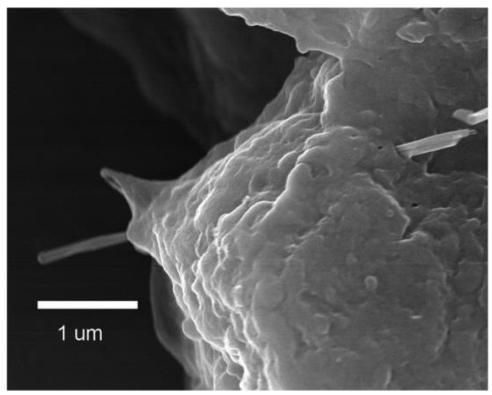
In many of these studies the nanoparticles were modified to prevent them from agglomerating together into particles larger than 2-3 microns. Some studies have shown that the primary effect of nanoparticles in the lung was asphyxiation when the particles clumped together and physically blocked the airways. The actual impact of a nanoparticle encountered in the workplace will depend critically on whether or not that nanoparticle agglomerates prior to or after entering the body.

Inhalation Hazards

The growing body of research into the hazards of inhalation exposure of nanomaterials demonstrates the potential for unwanted health outcomes *IF* there is exposure. Not all types of nanoparticles have demonstrated these hazards and not all the research has been done on

Certain nanomaterials can

- Induce cancers, including mesothelioma
- Cause rapid and persistent pulmonary fibrosis
- Cause cardiovascular dysfunction
- Migrate along the olfactory nerve into the brain



Alveolar Epithelial Penetration by Multi-walled Carbon Nanotube

Courtesy of R. Mercer, NIOSH

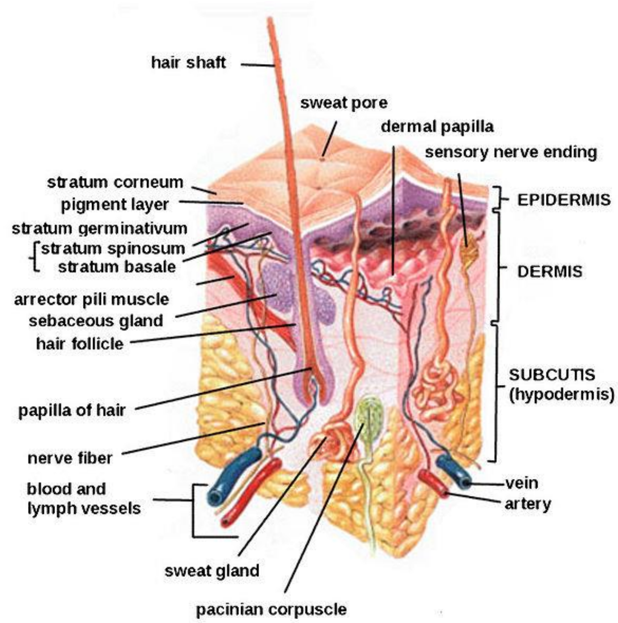
commercially relevant forms of the nanoparticles. With those caveats in mind here are some examples of significant findings from the hazard literature. The image shows a multi-walled carbon nanotube penetrating the alveolar epithelium. This is significant because it suggests that MWNTs that get into the lung have the potential to penetrate the epithelium and get into the space where mesothelioma originates.

Sources

- *Mesothelioma: Nature Nanotechnology 3, 423 - 428 (2008) and The Journal of Toxicological Sciences Vol. 33 (2008) , No. 1 February 105-116*
- *Cardiovascular: Environ Health Perspect 115 (3): 377–382 (2007)*
- *Olfactory: Journal of Nanoscience and Nanotechnology, 9(8): 4996-5007 (August 2009) and Environmental Health Perspectives Volume 114, Number 8, August 2006*

Routes of Exposure: Dermal

Research on skin as a route of exposure is more limited than that on inhalation. The methods for measuring skin penetration are still evolving and better validation and standardization are needed.



Dozens of papers demonstrate the ability of intact skin to protect against penetration of nanoparticles beyond the surface layers of the skin. This is particularly evident for titanium dioxide and zinc oxide nanoparticles used in topical sunscreens.

Fluorescently tagged polysaccharide (dextran) beads of 500- and 1000-nm diameter were found to penetrate to the dermis when the skin was mechanically flexed. Silver nanoparticles embedded in a wound dressing caused elevated levels of silver to be detected in plasma and urine and graying of the skin (argyria) of a burn patient.

Quantum dots of various sizes, surface coatings and shapes were found to penetrate intact skin to the epidermal and dermal layers within 8 hours. The researchers concluded that the time scale (typical work day) and dosage were relevant for occupational exposures.

Sources

- *Int Arch Occup Environ Health (2009) 82:1043–1055*
- *IMAGE: http://en.wikipedia.org/wiki/File:HumanSkinDiagram.jpg*

Dermal Hazards

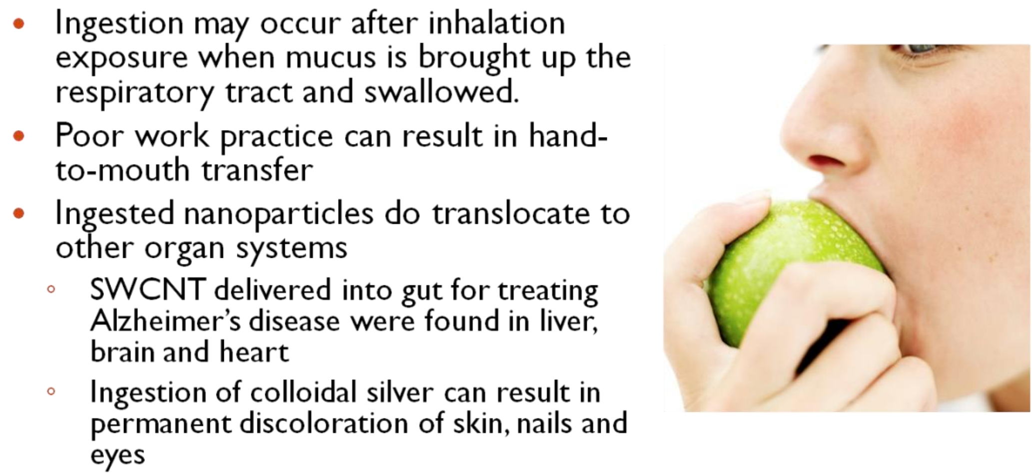
Various nanoparticles have been shown to

- Inhibit cell proliferation (iron oxide, nanotubes, TiO_2, silver)
- Affect cell morphology (silver, nanotubes)
- Initiate irritation response (quantum dots, nanotubes)
- Damage cell membrane (fullerenes)
- Induce DNA damage (cobalt chrome alloy)

Source

- *Review of dermal toxicity literature: Int Arch Occup Environ Health (2009) 82:1043–1055*

Routes of Exposure: Ingestion



Unintentional ingestion of nanoparticles may result subsequent to inhalation when mucus moves up out of the respiratory tract and is swallowed. (This clearance mechanism is called the mucociliary escalator.)

And, as is the case with other substances in the workplace, poor work practices, such as eating or smoking in the work area, can result in unintentional ingestion.

Occupational exposure via ingestion is perhaps the least well researched of the three pathways discussed in this module. However, the use of nanoparticles as drug delivery agents is a huge area in medical research. Some of these agents are meant to be ingested and then translocate to other areas of the body. This in itself demonstrates that ingested nanoparticles have routes out of the digestive tract and into other bodily systems. For example recently a single-walled carbon nanotube (SWCNT) agent introduced into rodent stomachs through gastrogavage was subsequently found in the liver, heart and brain as well as the lower intestine.

Excess ingestion of "colloidal" silver (much of which contains nanosilver) can result in a permanent discoloration of the skin (argyria) and eyes (argyrosis) from silver depositing into these tissues.

Sources

- *SWCNT: Nanomedicine: Nanotechnology, Biology, and Medicine 6 (2010) 427–441*
- *Silver: Journal of Applied Biomedicine 2008, 6(3): 117-129*

Ingestion Hazards

Various nanoparticles have been shown to

- Slightly damage liver (silver)
- Trigger immune response in intestinal dendritic cells (TiO_2 and SiO_2)
- Be cytotoxic to human intestinal cells (TiO_2, SiO_2 and ZnO)
- Damage DNA of human intestinal cells (ZnO)

- Be genotoxic to liver and lungs after oral adminstration (C_{60} and SWNT)

There is limited research about the effects of nanoparticles post-ingestion. However, some studies indicate that certain nanoparticles have the potential to damage intestinal cells and, after translocating out of the gut, induce unwanted health effects in other organs. This research is too preliminary to draw major conclusions and most papers conclude that more research is needed to better understand the effects of ingested nanoparticles.

Sources

- *Silver liver damage: Particle and Fibre Toxicology, 2010, 7:20 (11 pp)*
- *Intestinal dendritic cells: Nanotoxicology, 2010 Early Online, DOI: 10.3109/17435390.2010.506957*
- *Cytotoxic: Nanotoxicology, 2009 3(4): 355-364*
- *DNA damage: Nanotoxicology, 2009 3(4): 355-364*
- *Genotoxicity: Environ Health Perspect 117(5), 703-708 May 2009*

Conclusions

- Much of the early nanoEHS research has focused on simple systems of limited relevance to human health (e.g., cytotoxicity)
- Some nanoparticles can translocate throughout the body after exposure via inhalation, contact with skin or ingestion
- Some nanoparticles can induce unwanted health effects in animals or cell cultures

It makes sense to control exposure to those nanomaterials for which preliminary hazard data show unwanted health effects or hazards are unknown.

Module 3: Assessing Exposure to Nanomaterials in the Workplace

Lesson Overview

The purpose of this module is to provide nanoworkers with a basic awareness of sampling and analytical approaches being used for nanoparticles, the limitations of the results and the viability of alternative hazard assessment methods.

These topics will be covered:

1. Methods currently being used to sample and analyze nanoparticles
2. Value of standard IH procedures and equipment for nanoparticle sampling
3. Use and limitation of sampling data
4. Status on NIOSH, OSHA and international occupational exposure limits

Learning Objectives

At the end of this module you will be able to

- Compare and contrast standard IH sampling and analytical methods with those used for nanoparticles;
- Describe the equipment used for nanoparticle sampling and analysis;
- Evaluate sampling results and compare them to recommended occupational exposure limits; and
- Discuss the limitations of nanoparticle sampling and analysis.

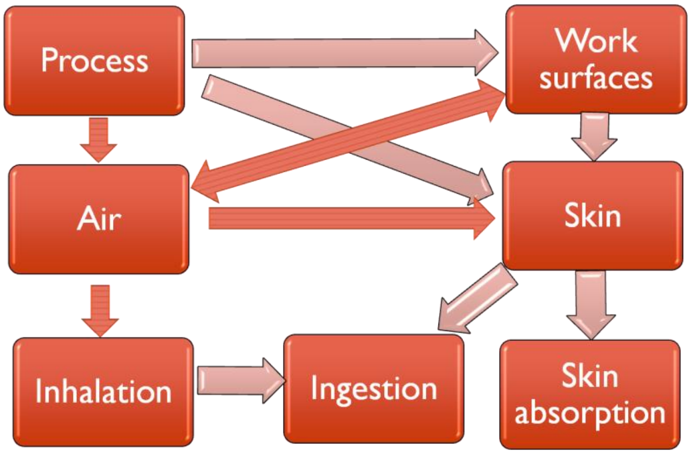
Important Quotes

"In the long term, nanotechnology will demand a revolutionary re-thinking of occupational health and safety." John Howard, MD, NIOSH

"It is likely that no single metric will completely characterize exposure." Linda Abbott and Andrew Maynard, Risk Analysis, 2010

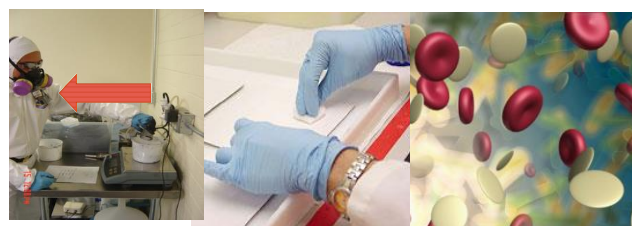
Special thanks to NIOSH for their kind assistance and particularly to Charles L. Geraci, Jr, Ph.D., CIH, Coordinator, Nanotechnology Research Center for the generous use of his slides.

Let's start with an exposure pathway model (Mulhausen and Damiano).



Monitoring is classified as personal, area or biological.

Personal monitoring is the most common but area and biological monitoring also serve important purposes in ensuring occupational health.



personal area biological

Area monitoring determines concentration at a location over time.

Area monitoring is often used to measure concentration in ambient air prior to, during or after a job or event. Area monitoring can be used to establish background concentrations, trigger alarms in the event of elevated concentrations and monitor long-term changes in air quality.

Photo: area monitoring during transfer of carbon nanotubes. (Courtesy NIOSH)

Wipe sampling is another form of area monitoring.

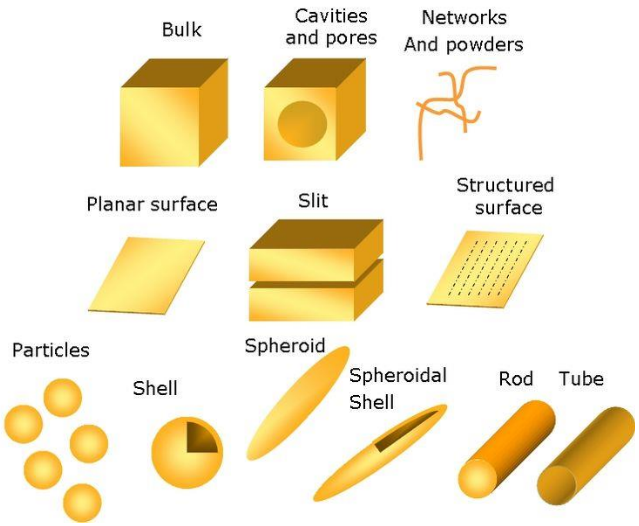
Instead of sampling a known volume of air, a known surface area is sampled or wiped. Notice the template being used to ensure the area sampled is consistent between samples. A clean template should be used for each sample to reduce the likelihood of contaminating samples.

Biological monitoring measures contaminants, metabolites or enzymes in the blood, urine or exhaled breath.

What does NIOSH recommend for nanoworkers?

Group exercise: What could we sample?

Working with your group, discuss what industrial hygiene sampling method you know about and whether they could be applied to nanoparticles. Specifically consider these various structures of nanoparticles.



Typical nanostructure geometries. Illustration courtesy the Opensource Handbook of Nanoscience and Nanotechnology.

What should we sample?

Metric	Qualification
Mass	**Not always relevant**
Surface area	**Better for low solubility particles**
Surface chemistry	**Tox studies show effects**
Particle number	**Within ranges**
Particle size	**Implicated in particles translocating**
Particle shape	**Fiber-like, spheres, mats**

Can we use standard industrial hygiene methods? Yes ☐   No ☐

Respirable dust sampling

Pre-weighed cassettes for gravimetric sampling

Active sampling uses pumps to pull contaminated air through appropriate media.

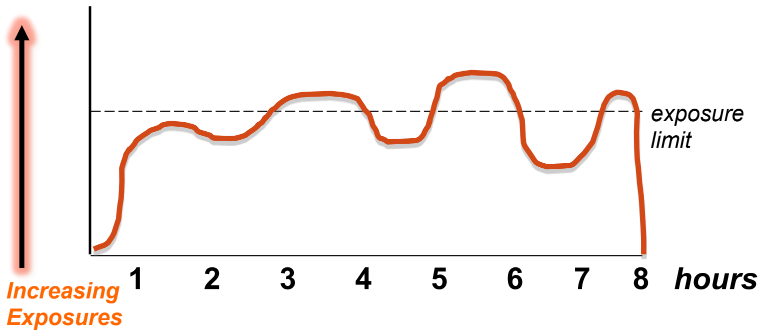
Pumps are generally classified as “high flow” if they draw more than 1 liter per minute and “low flow” if they draw less than 1 liter per minute.

Photo courtesy SKC

Personal pumps are hung on a worker’s belt with the media in the breathing zone.

Photo courtesy Lawrence Berkeley National Laboratory

Most exposure limits are based on 8-hour time weighted averages.



This includes NIOSH's recommendation for Carbon Nanotubes

Pumps must be calibrated before and after sampling.

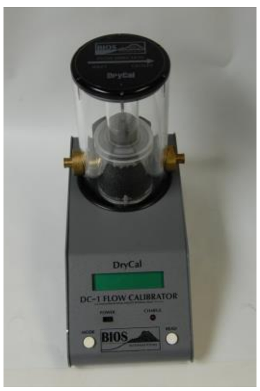
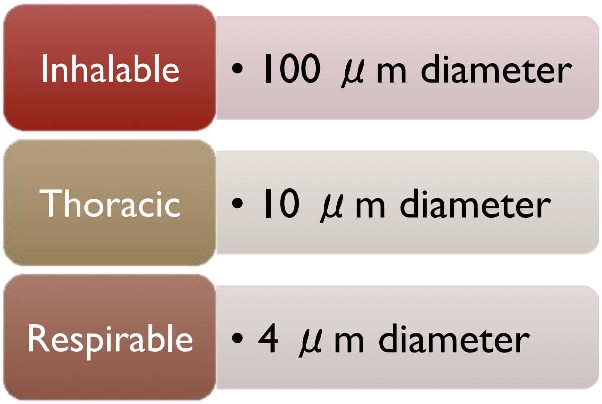


Photo courtesy SKC, Inc.

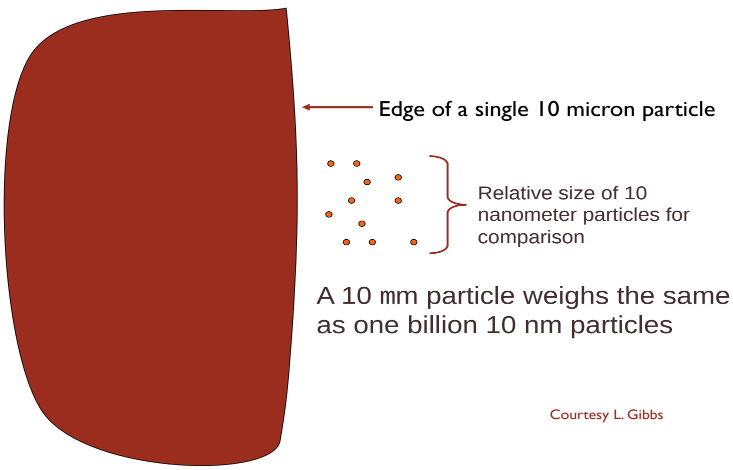
Calibration devices are classified as "primary" or "secondary". Primary calibration devices are preferred because they directly measure the dimensions of a physical space and are traceable to a standard. The National Institute of Standards Technology's (NIST) standards are the most common in the United States. Examples of primary calibration instruments include a glass bubble burette and an electronic dry piston meter, such as the units show here. Secondary calibration devices do not have a fixed volume, are likely to become less accurate with use and are not traceable to a NIST or other standard. Examples of secondary calibration devices include rotameters.

Calibration of sampling pumps should be performed before and after air sampling and with all sampling media inline. In most cases the post use flow rate is within a few percent of the pre use flow rate and an average flow rate can be determined. If the flow rates are more than a few percent different then we cannot be sure of the sample volume and the sample will likely be considered invalid.

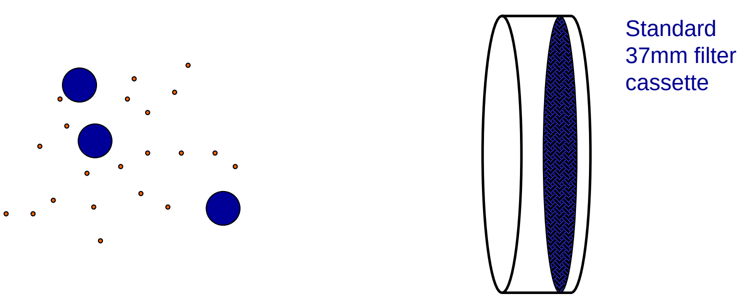
Particles are classified by their penetration. Where do nanoparticles fit?



Nanoparticles Have Almost No Mass



Large particles bias mass measurements



If you're carrying a grocery bag full of cantaloupes, you're not going to notice a handful of grapes

Courtesy L. Gibbs

Examples of Potential Exposures

Photos courtesy of M. Methner, NIOSH

NIOSH recommends a graded approach to measurement.

Step 1: screen area and process
Particle counters and simple size analyzers

↓

Step 2: collect samples at source
Filter based samples for EM and elemental analysis

↓

Step 3: collect personal samples
Filter-based samples for EM and elemental analysis

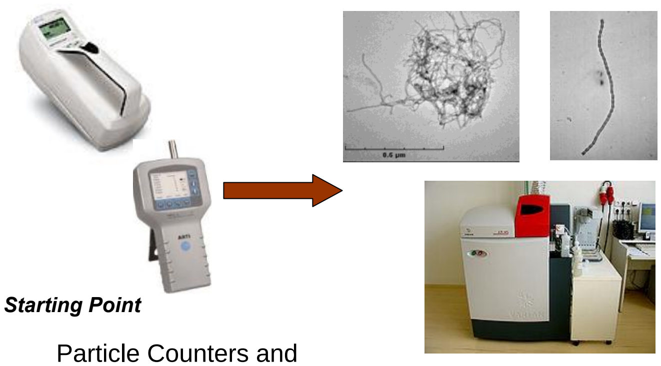
↓

Step 4: use less portable equipment
More sensitive aerosol sizing equipment

NIOSH's Nanoparticle Emission Assessment Technique (NEAT) has several key strategies:

1. Start with a semi-quantitative initial assessment to compare particle numbers at sources to background numbers.
2. If warranted, move on to an extended investigation using less portable, more expensive analyzers.
3. Use the criterion that significantly higher readings when production system is on indicate a problem.

NEAT correlates simple and complex measurements.



Particle Counters and
Size Analyzers

The NEAT protocol has some difficulties.

- The TEM samples can be overloaded with other airborne materials, as was learned at the World Trade Center where many samples had to be voided because of the amount of material in the air.
- NIOSH recommends collecting samples under NEAT at 7 liters per minute for the duration of the task, which often is short. This flow rate favors larger pumps and area sampling; personal sampling is usually at 2 liters per minute.

NEAT instrumentation

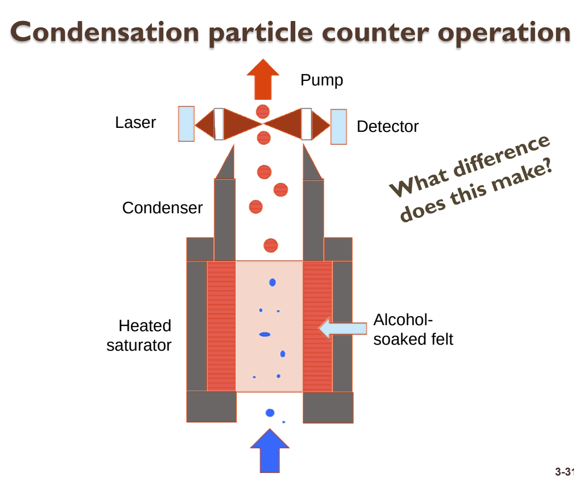
TSI 3700 CPC

- **Condensation Particle Counter (10 -1000nm range, p/cc)**

TSI Aerotrak 9303

- **Optical Particle Counter (300-10,000nm, p/l)**

Condensation particle counters have been used for a long time to perform quantitative fit testing. The technology uses alcohol to coat particles, which renders them large enough to count with a laser. This also allows the counting of smaller particles than the optical counter.



The TSI AEROTRAK 9303 Handheld Particle Counter is an example of the latter type. It has an internal memory that can store up to 1,500 sample records of particle count data that can be viewed on screen or downloaded using a USB port. The instrument reports up to 3 particle sizes simultaneously and comes with an internal alarm. It measures particles in the size range 0.3 - 10µm at a flow rate of 2.8 liter per minute.

Scanning mobility particle sizers provide more data, but are more difficult to use in the field.

Scanning Mobility Particle Sizers (SMPS) feature an electrostatic classifier and a Condensation Particle Counter (CPC). This provides the possibility of many configurations. SMPS systems measure particles from 2.5 to 1000 nm and display data using up to 167 actual size channels. There are several manufacturers available, but all share an increased cost over the hand-held devices and a great deal less mobility, even though they produce more comprehensive results.

In their 2010 draft Current Intelligence Bulletin on carbon nanotubes, NIOSH has recommended NIOSH Method 5040 to quantify exposure to airborne carbon nanotubes. The method requires:

- 37 mm quarts fiber filters
- Flow rate of 2 to 4 liters per minute
- Size selective samplers may be needed
- Reporting as elemental carbon

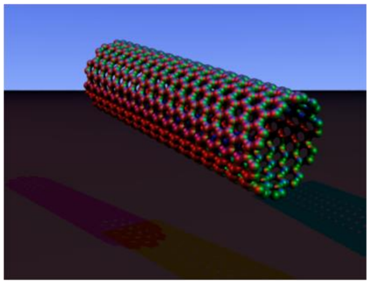
NIOSH chose mass-based REL over counting with electron microscopy because:

- Animal toxicology studies are mass-based; and
- Counting protocols haven't been developed, although ASTM has a committee working on a TEM protocol.

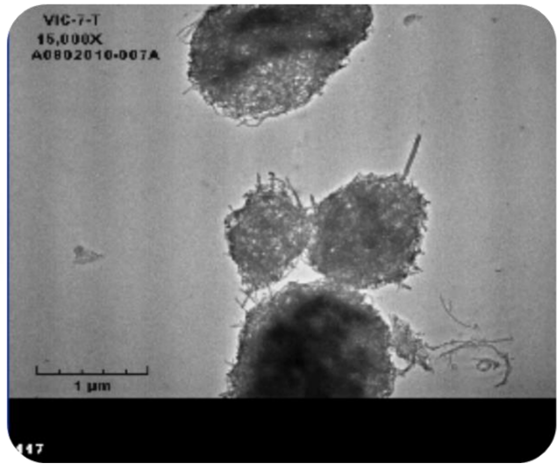
But mesotheliomas have been produced in mice with MWCNTs that are fibers with long aspect ratios. (Takagi 2008, Poland 2008)

Multi-walled carbon nanotube penetrating the pleura of the lung.
Courtesy of Robert Mercer, and Diane Schwegler- Berry, NIOSH

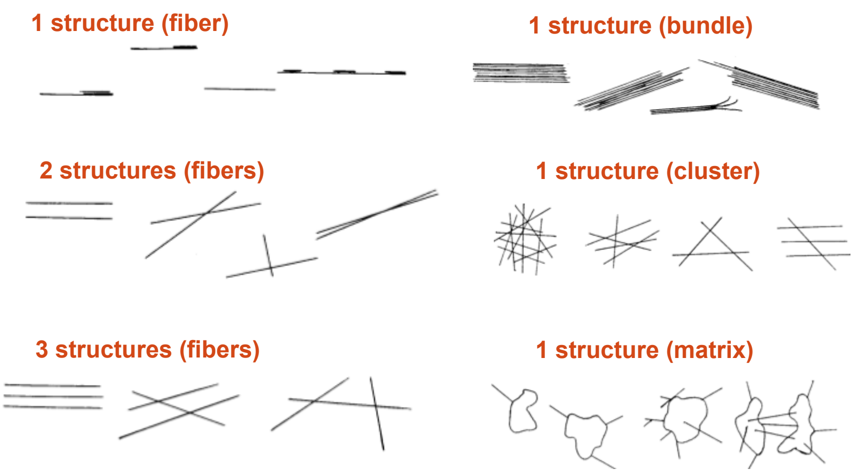
NIOSH says 10,000 carbon nanotube combinations are possible. The standard computer graphic is not representative of what is often seen, like the image below.



≠

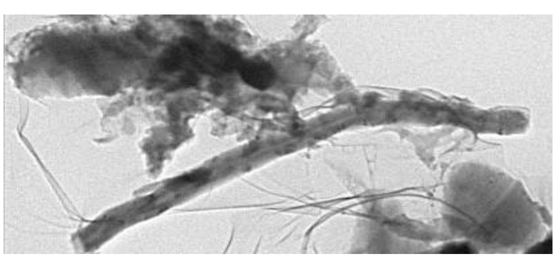


The CNT counting protocols will be similar to asbestos TEM methods now in place.

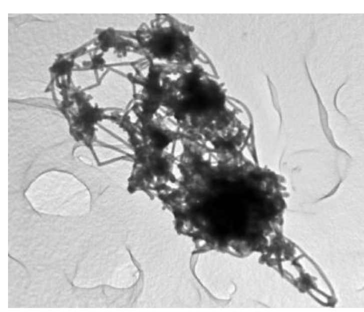


EPA AHERA Method Appendix A to Subpart E of Part 763

Categorize and count the following structures.

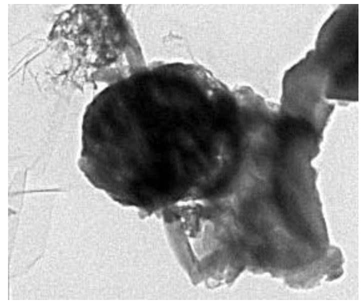


1. ______________



2. _______________

3. ______________



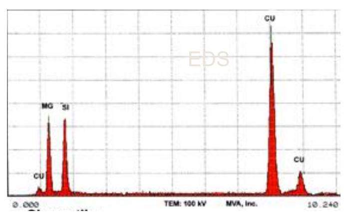
4. ____________

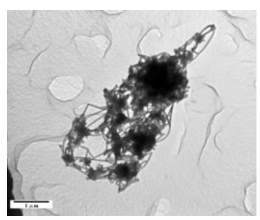
Electron microscopy is the gold standard. It allows:

- Characterization of bulk material for comparison to airborne particles
- Indication of the presence of specific engineered nanomaterial (ENM)

TEM allows several measurements.

- Morphology
- EDS (EDXA) for chemical composition
- Particle count
- Particle length and diameter



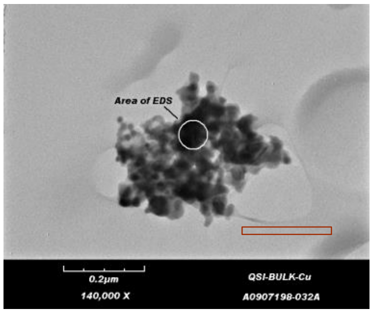


Elemental analysis for metals allows better characterization.

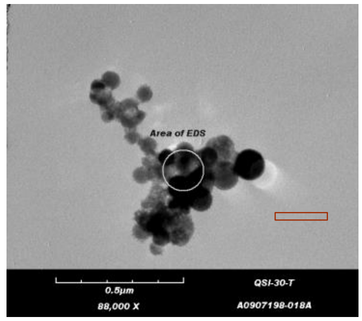
- NIOSH recommends sampling high emission areas: both breathing zone and area
- Conduct elemental analysis (NIOSH 7300, metals with ICP)
- Characterize and verify by TEM

Raw single walled nanotubes, photo courtesy NIOSH

NIOSH analysis of metal reactor cleanout provides good example of EM capabilities. Note the obvious visual similarity between the bulk product and a particle collected on an air sample during the cleanout operation.



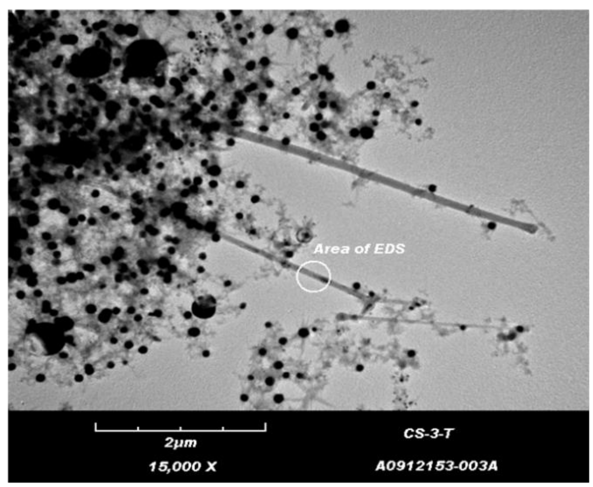
Bulk product sample



Air sample

Harvesting SWCNTs from a Carbon Arc Reactor

Task-based BZ air sample analyzed via TEM w/EDS



There are no OSHA PELs, but there are several recommended OELs.

Adapted from Schulte et al. Journal of Nanoparticle Research, 12(6): 1971-1987, 2010.

Nanomaterial	OEL	Ref.	Year
Titanium dioxide	0.3 mg/m^3 ultrafine 2.4 mg/m^3 fine	NIOSH REL	2011
Photocopier toner	0.06 mg/m^3	BAuA	2009
CNTs	0.01 f/cm^3	IFA	2009
Fibrous (3:1 aspect ratio, length 75,000 nm)	0.01 f/cm^3	BSI	2007
MWCNTs	0.05 mg/m^3	Bayer only	2010
MWCNTs	0.0025 mg/m^3	Nanocyl only	2009
CNTs and nanofibers	0.007 mg/m^3	NIOSH Draft REL	2010
CNTs and nanofibers	0.001 mg/m^3	NIOSH REL	2013

Let's review the sampling approach at the Oak Ridge Center for Nanophase Materials Research

Potential Group Exercise:

In your group review a sampling report and answer the following questions:

1. What kinds of samples were collected?

2. What media did they use?

3. What method did they use to analyze them?

4. What types of structures did they find?

5. Is there anything in the report that you don't understand?

Module 4: Controlling Exposure to Nanomaterials

Lesson Overview

The purpose of this module is to provide nanoworkers with a basic awareness of the hierarchy of controls and its application to eliminate or reduce exposures to engineered nanoparticles. Every level of the hierarchy will be addressed in this module: elimination, substitution, engineering controls, administrative controls and personal protective equipment.

These topics will be covered:

1. The concept and importance of the hierarchy of controls
2. Elimination and the difficulties of substitution
3. Local exhaust ventilation as the primary engineering controls for nanoparticles
4. High efficiency particulate filters
5. Personal protective equipment as the last line of defense against nanoparticle exposures
6. The fire hazards of nanoparticles

Learning Objectives

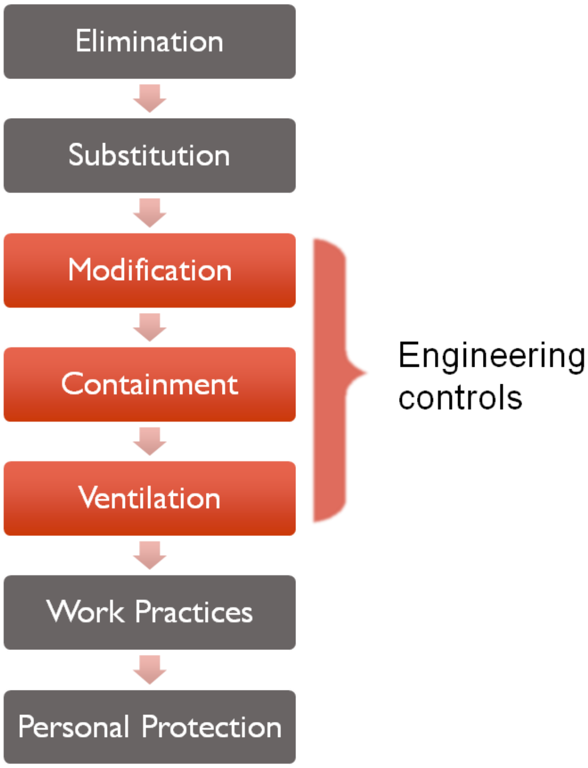
At the end of this module you will be able to

- Explain the hierarchy of controls and how to apply it to nanoparticles
- Describe the difficulties with substitution
- Describe how a HEPA filter works and its effectiveness against nanoparticles
- Discuss which ventilation systems work best for nanoparticles
- Describe the respiratory protection used by nanoworkers
- List NIOSH's PPE recommendations for nanoworkers
- Differentiate between qualitative and quantitative fit testing
- Don and doff an elastomeric half-face respirator and/or an N-95 filtering facepiece respirator

Topic 1: The concept and importance of the hierarchy of controls

This model has underpinned industrial hygiene control efforts for a long time.

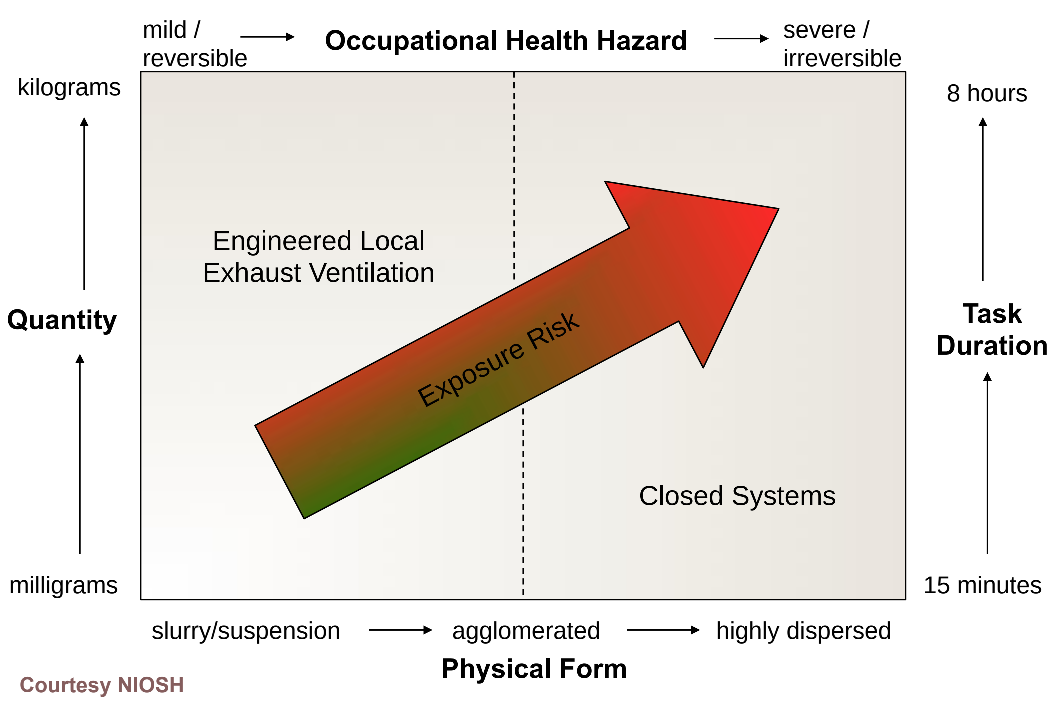
The controls are listed in decreasing order of preference. Modification, containment and ventilation are considered engineering controls and will be discussed in this presentation. Elimination and substitution are preferred over engineering controls. Work practices, or administrative controls, and personal protective equipment are less desirable controls than engineering controls and will be discussed in the near future.



http://www.cdc.gov/niosh/topics/ctrlbanding/images/hierarchy_of_controls.jpg

How do we actually apply the hierarchy to engineered nanoparticles?

We need to consider these factors.



Topic 2: Elimination and the difficulties with substitution

Elimination

Why would we eliminate nanoparticles? Why is this the least practical control approach?

Evaluation showed that the product released nanoparticles into the environment.

The added benefits were just marginal and the unknown risks weren't acceptable.

Health complaints were being received from users of the product that may have been associated with the nano-sized component.

Substitution

Is substitution more likely than elimination?

What are possible difficulties with substitution?

Substitution isn't as easy as it sounds.

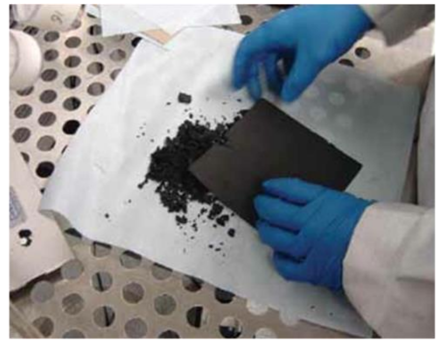
This chart, courtesy Michael Wilson, UC Berkeley, shows serial substitutions of solvents and why they needed to be replaced. Each of the solvents was replaced by another chemical that later proved to pose risks, too.

Year	Substitute Solvent	Reason for replacement
1970	Stoddard solvent	Fire hazard
1978	CFCs	Ozone depletion
1980	Methylene Chloride	Carcinogen
1985	1,1,1-Trichloroethane	Ozone depletion
1990	Perchloroethylene	Dioxin emissions
2002	Hexane/acetone blends	Neurotoxin
Next	1-Bromopropane	Reproductive toxicant

Engineering Controls: Modification

What modification could we make to a process to reduce airborne nanoparticles?

Nanoparticles are often provided and worked in a wet state to reduce the risks of exposures.



Would this crumbling carbon nanofiber paper present less risk if the material were kept wet?
Photo courtesy Mark Methner, NIOSH

Engineering Controls: Containment

What are some examples of containment for nanoparticles?

Nanocomp (a firm in New Hampshire) produces CNTs in these enclosed furnaces.

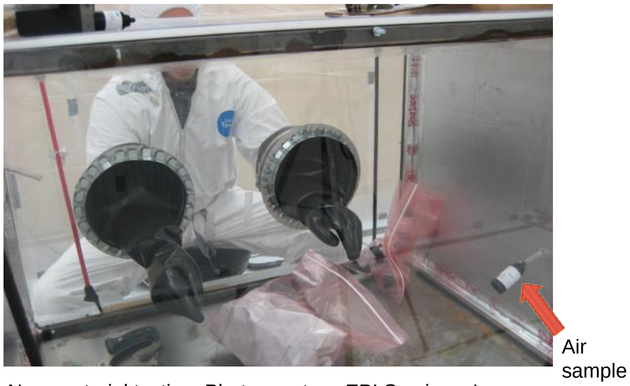
Photo courtesy NIOSH and Nanocomp Technologies, Inc.

Manufacturing Containment

This shows the ventilation pulling from all of the furnaces up through a high-efficiency filter and then outside.

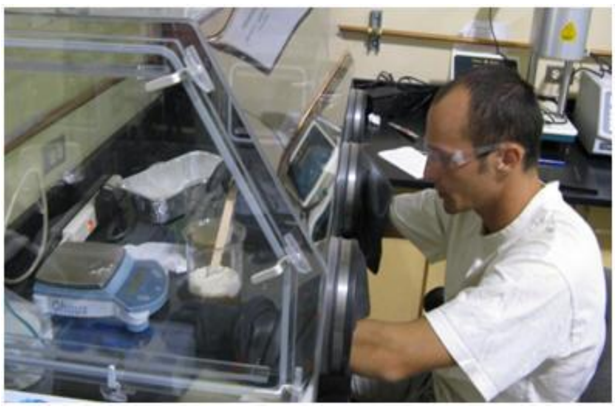
Photo courtesy NIOSH and Nanocomp Technologies, Inc.

Gloveboxes are a type of containment being used for handling nanoparticles.



Nanomaterial testing. Photo courtesy EPI Services, Inc.

Gloveboxes inside a 'Nanoparticle Containment Room"



Texas State University does not allow the use of carbon nanotubes in glove boxes with other materials, but instead isolates the operation in a portable clean room referred to as the 'Nanoparticle Containment Room'.

The Ingram School of Engineering has spent about $6000 on the glove box and $15,000 on the 'Nanoparticle Containment Room'. The following are the highlights of this nanoparticle containment room.

This is 8' x 10' hard-wall, ready-made clean room. This room maintains negative pressure and there is dedicated exhaust to this room (with blower on the roof). The filters used are ULPA (Ultra-Low Penetration Air) Filters rated 99.999% efficient with particles 0.12 microns (120 nm) in diameter. Traditional HEPA filters are good up to 0.3 microns (300 nm) with rated efficiency of 99.97%.

Researchers who would like to use this room have to wear half-mask respirator, lab suit, and other personal protected equipment (PPE). All these people will have to pass pulmonary function test and undergo respirator training.

"Handling dry nanoparticles in open atmosphere is not allowed."

Nanoparticle Containment Room, Texas State University

Also note the nano warning sign. It isn't required or defined by any consensus standard, but shows good practice. The quote, "Handling dry nanoparticles in open atmosphere is not allowed" is Texas State University policy.

Work practices and PPE will still be needed when enclosures are opened.

Although we have shown excellent enclosures, it is critical to understand that all enclosures need to be opened to remove product, wastes or for maintenance and cleaning. Consequently, work practices are needed.

Harvesting SWCNTs from a Carbon Arc Reactor

Topic 3: Local exhaust ventilation as the primary engineering controls for nanoparticles

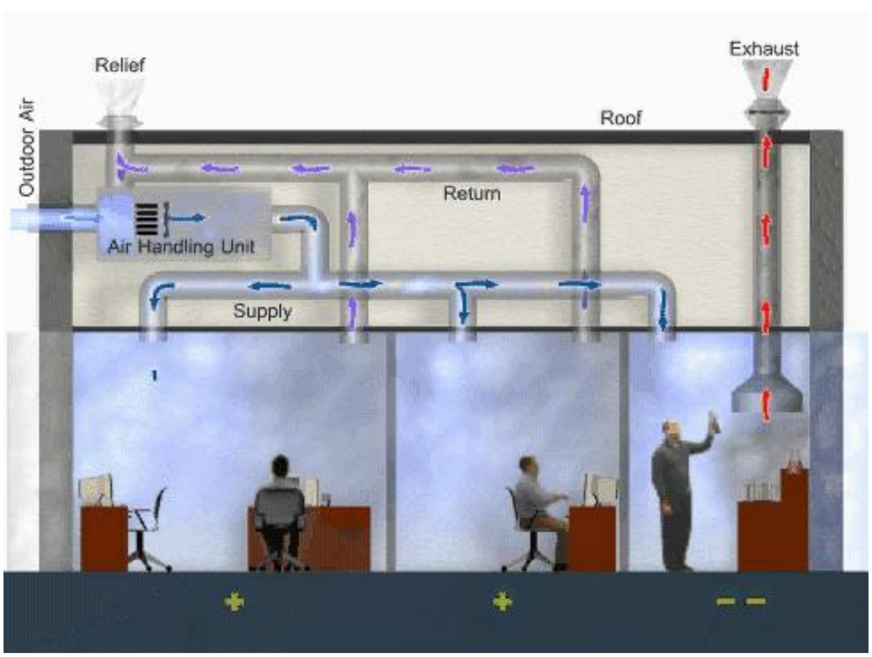
What are the two main divisions?

1) Dilution ventilation

2) Local exhaust ventilation

Dilution ventilation is okay for nonhazardous exposures, but isn't acceptable for nanoparticles. Dilution ventilation is used to control less hazardous exposures and to provide conditioned air.

Dilution ventilation supplies some outdoor air, but mostly recycles room air. What about the lab?



http://www.epa.gov/iaq/largebldgs/i-beam/visual_reference/series_1/index.html

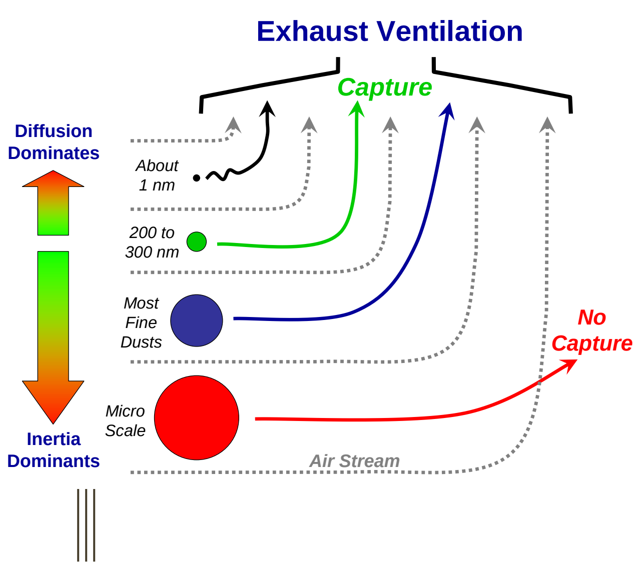
Dilution ventilation supplies outdoor air. This graphic shows a functioning dilution ventilation system with local exhaust ventilation in the right most room. The air-handling unit mixes outdoor air with return air and conditions it before it is supplied to each of the rooms. Conditioning may include heating, cooling or adjusting the humidity of the air. Notice that the air enters each room on one side and leaves on the other side to ensure good mixing. The plus signs below the left two rooms indicate the pressure in these rooms is greater than the right most room, which has negative signs below it. Higher pressure in the offices ensures that if there are leaks between them and the laboratory that air will flow into the lab and minimize the number exposed.

Local exhaust ventilation (LEV) controls hazardous exposures.

New Lab hood in the University of Puerto Rico

Lab hoods need to be tested for face velocity and the sash height marked. Any safety issues here?

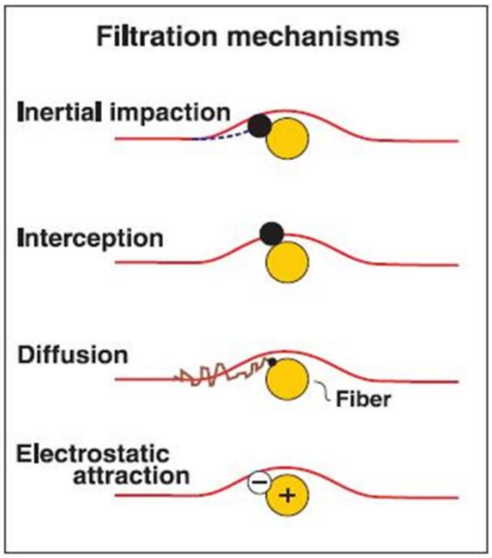
Lab hoods also need to be checked routinely for maintenance.



This graphic from NIOSH shows that nanometer-sized particles are captured with local exhaust ventilation, primarily through diffusion. However, with particles that are in the micro scale, the forces of inertia may keep them from following the air stream as it turns to go towards the hood.

Method of particle capture

This graphic shows an individual fiber in a filter and the manner that particles are captured onto the fiber. The very small particles are captured by diffusion. Capturing with a charge, i.e. electrostatic attraction, only works with smaller particles. It is the principle of filtration for N-95 filtering facepiece respirators, which have media that are charged.

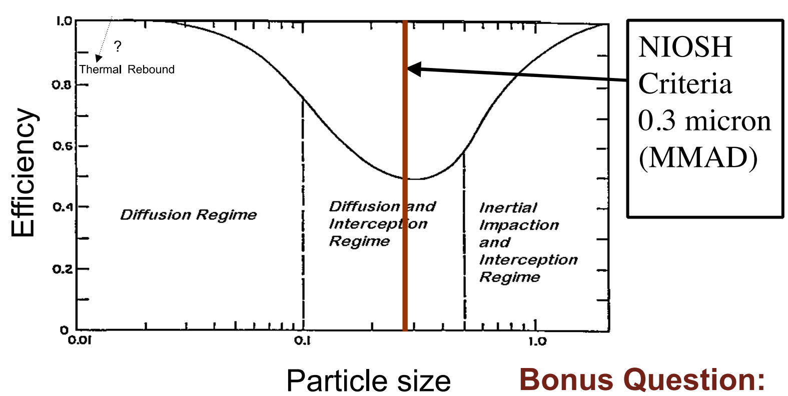


Courtesy Roland Berry Ann, NIOSH

Topic 4: High Efficiency particle filtration

What is the most penetrating particle size?

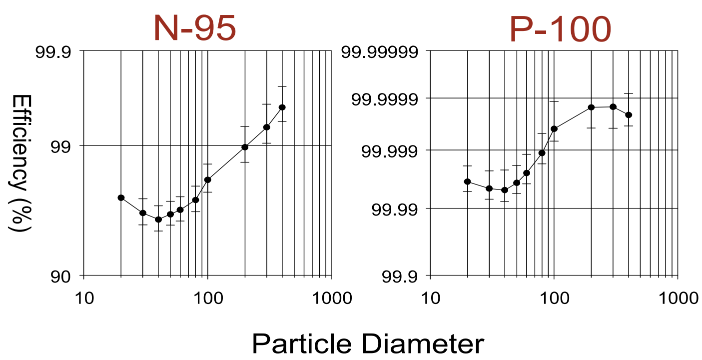
This graph points out the reason HEPA is defined as a filter that is 99.97 percent efficient at a 0.3 micrometer Median Mass Aerodynamic Diameter. That is the toughest particle size to capture because it is too small to catch with impaction, but too large to operate by diffusion. It operates under Brownian Motion. Consequently, if you can capture particles of 0.3 micrometer dimension at 99.97% efficiency, you do better with larger particles and with smaller partlcles, as this graph indicates.



Courtesy NIOSH

Bonus Question: What is HEPA?

With nanoparticles between 20 - 400 nm, 40 nm is the most penetrating size.



This is a test that was done with particles between 20 and 400 nanometers in diameter and the most penetrating for both the N-95 and P-100 was around 40 nanometers, but just like we saw on the other graph, smaller and larger particles were both captured more efficiently.

LEVs need to be very close to the source.

Capture ability drops off dramatically unless the face is close to the particles.

Cleaning of metal oxide reactor with LEV use.

Photo courtesy Mark Methner, NIOSH

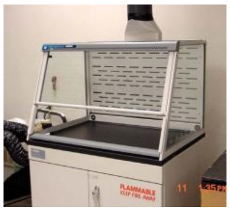
ICON surveyed means of control for firms and labs in 2006:

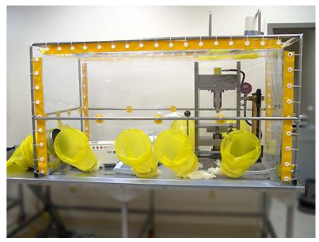
An international survey by the International Council on Nanotechnology (ICON) of manufacturing firms and research labs found that the principal means of controlling exposure are:

- 43% laboratory hoods,
- 32% glove boxes,
- 23% vacuum systems,
- 23% white rooms,
- 20% closed circuits,
- 15% laminar flow ventilation tables,
- 12% biosafety cabinets and
- 12% glove bag.

Effective controls for lab-scale work are available.

Two of these units are disposable and cheap. Not all ventilation units have to be expensive and permanent.





Larger scale controls can work for nanoparticles.

Mixing of CNFs inside ventilated enclosure. Air is drawn underneath plastic strips and up to ceiling exhaust vents.

Photo courtesy of Mark Methner, PhD, CIH, NIOSH

Walk-in operations can still be kept under negative pressure and filtered through HEPA. In this image a worker is mixing carbon nanofibers inside a ventilated enclosure. Air is drawn underneath plastic strips and up to ceiling exhaust vents where it goes through a HEPA filter before being exhausted out of the building. NIOSH found that LEV use during reactor cleanout achieved significant reductions.

Reductions using local exhaust ventilation

Operation	Air conc w/o LEV	Air conc with LEV	% Reduction due to LEV
Mn reactor cleanout	3,619	150	96
Ag reactor cleanout	6,667	1,714	74
Fe reactor cleanout	714	41	94
Background prior to cleanout	ND	ND	n/a
Mean (+/- S.D.)			88 (+/- 12)

Administrative Controls: Work Practices

NIOSH found that work practices during cleanout made a real difference.

NIOSH found that during this furnace cleanout of carbon nanotubes, if the worker was less vigorous and brushed towards the LEV, the concentrations were much lower.

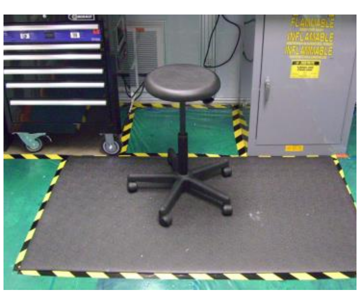
Work practices for cleanup at end of the shift:

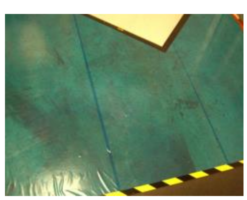
- Clean work areas using either a HEPA-filtered vacuum or wet wiping
- Clean in a manner that prevents contact with wastes
- Comply with all federal, state and local regulations when disposing of wastes
- Wash hands frequently, particularly before eating or leaving the worksite
- Wear assigned PPE and keep it maintained properly
- Use sticky mats and gowning procedures

Source: NIOSH and Oak Ridge National Laboratory

Sticky pads in lab

Special flooring includes tacky covering and sticky mats.





Photos courtesy Jitendra S. Tate, Ph.D., Professor, Texas State University San Marcos

This is inside the Nanoparticle Containment Room and shows a green floor that is a permanent, washable, tack-regenerating mat designed specifically for the removal of foot borne and wheel borne contamination. It covers the cracks and depressions in normal concrete flooring that hold contamination. In addition, there is a Sticky Mat which is a stack of sheets of polyethylene film, with a specially treated pressure sensitive adhesive on one side, upon which persons entering a cleanroom or clean zone walk (and vehicles are rolled) to remove the last trace of contamination on shoe heels and soles, and on wheels. When a sheet becomes loaded with contamination, it is peeled off, exposing a new clean sheet for use, thus eliminating messy and time-consuming cleaning and washing.

Topic 5: Personal protective equipment as the last line of defense against nanoparticle exposures

Why is PPE at the bottom?

Personal Protective Equipment Overview

Which level do you think we may need for handling nanoparticles?

Level A is a totally chemically impermeable suit with a SCBA inside the suit for maximum protection. Level B is also a self-contained breathing apparatus, but it is worn outside the suit so chemical penetration isn't as significant a threat. Level C is a protective garment, generally Tyvec with an air-purifying respirator. Level D is just a protective garment without a respirator. **The answer is that workers who handle nanoparticles will either wear Level C or Level D.** Working with self-contained breathing apparatus is overkill and the suits would not permit the kind of dexterity that is needed for most work with nanomaterials in a lab or production operation.

Image courtesy of Kirkwood Community College

Tyvec is the most widely used body covering for nano operations.

This is a shot of a researcher at EPI Services, Inc. about to perform some testing of a product containing nanoparticles. Note that he is wearing a half-face respirator with High Efficiency cartridges (purple) combined with ammonia protection (yellow). He is also wearing a personal sampling pump (out of view) attached to a 25 mm diameter cassette holding a 0.45 micron porosity mixed cellulose ester filter. The black cassette is taped in his breathing zone. Note, too, that he has donned his respirator *before*

pulling up his hood. This is the correct way to do it. If the straps are on the outside, it forces you to remove your respirator to take off the suit.

NIOSH recommends wearing hand protection when working with nanoparticles.

There is limited data indicating penetration of the skin by nanoparticles, but cuts in the skin may offer an easier path. Disposable nitrile gloves are the most widely used because they provide protection against a wide range of chemicals, but it is important to check what glove is recommended for specific chemicals. This can be found at most manufacturers' websites.

- Nitrile (most generally used)
- Neoprene
- Polyvinyl chloride (PVC)
- Latex

Eye protection may also be necessary.

When would goggles be preferred over safety glasses?

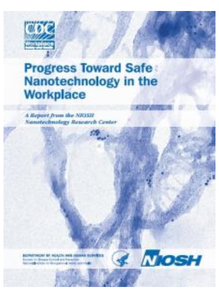
All must meet a specific standard from the American National Standards Institute called ANSI Z-87.1

Respirators may be required for some nano operations. If so, OSHA's respirator standard, 1910.134, would apply.

This would mandate that the company have a written program and provide training, medical evaluations and fit testing to workers.

NIOSH found no evidence of nanoparticles passing through respirator filters at a higher rate.

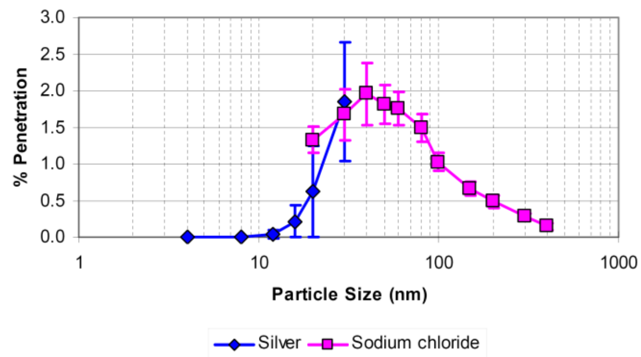
Flat plate tester



U. of MN tested respirator filter media to 3 nm

FROM the NIOSH 2-07 report, "Progress Toward Safe Nanotechnology in the Workplace": This device is a flat plate test system for measuring respirator filter penetration of 3 to 20 nm silver particles. Scientific information is available to characterize the efficiency of respirator filtration for particles larger than 20 nm in diameter. However, less is known about smaller particles. To increase knowledge and understanding of these smaller particles, NIOSH funded a study in 2005 at the University of Minnesota's Center for Filtration Research. The purpose of this study was to measure the penetration of nanoparticles between 3nm and 20nm in size through various filter media, including glass fiber, electret, and nanofiber. The respirator filter media tested in this study effectively collected nanoparticles down to 3nm in size. There was no evidence that particles in this size range pass through filter media at a higher rate than the larger particles

Filtration performance of an example NIOSH approved N95 filtering facepiece respirator



n = 5; error bars represent standard deviations
TSI 3160; Flow rate 85 L/min

The % penetration (vertical axis) is the opposite of % efficiency. A 95% efficient respirator would by definition have a 5% penetration. Note that the smallest sizes (which were of greatest concern because of a phenomenon called thermal rebound) have the least penetration. The particle size with the greatest penetration is around 40-50 nm, which is what we saw earlier.

Respirators can be divided into two broad classes.

Respirators can be divided into two broad classes: air supplying and air purifying.

If you don't have to filter the air, it is safer for the worker.

Courtesy Kirkwood Community College

Another key difference is the pressure inside the mask when inhaling.

A respirator like the N-95 becomes slightly negative when the wearer takes a breath. If there is a leak anywhere around the face-to-facepiece seal, the air will go through the opening rather than through the mask's filtration media. With a mask like the powered air purifying respirator (PAPR) shown, even though it is still filtering air like the N-95, it maintains a positive pressure inside the face-piece because of a battery-powered fan that constantly blows air into the mask. This makes a major difference. The N-95 is given an applied protection factor of 10, while a tight fitting PAPR like that shown is given an applied protection factor of 1,000. So obviously the PAPR offers more protection.

Respirators can be further divided based on facial coverage.

- Full-face

- Half-face

Which offers more protection? Why?

Respirators are either full-face or half-face. A full-face respirator isn't given additional points for eye protection, but they have a major design advantage: they go across the forehead. Building a respirator that goes across the forehead is much less problematic than trying to cover the bridge of the nose where there is much greater human variation. Not surprisingly, the greatest leakage occurs at the bridge of nose.

Courtesy Kirkwood Community College

Consequently, OSHA gives half-face respirators an applied protection factor of 10 while full-face are given 50.

EPA requires full-face N-100 cartridge respirators for CNT manufacturers under a consent order, unless they prove no exposure.

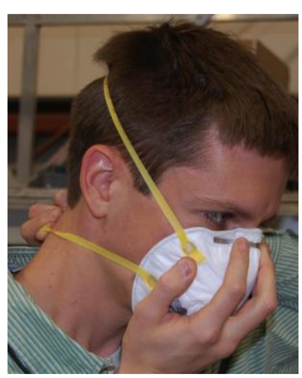
MSA **Full-face Respirator**
Courtesy MSA

North **Full-face Respirator**
Courtesy North Corporation

Fitting an N-95 disposable respirator

1. Place on face

2. Fit top strap on crown



3. Place bottom strap on neck

4. Press nose clip in place with both hands

OSHA requires that workers pass a fit test *before* wearing a respirator.

A worker has no idea if a respirator fits unless it is tested. OSHA accepts either quantitative or qualitative. The picture shows a blue Portacount unit that measures the number of particles outside the respirator and then inside the respirator and provides a protection factor by dividing the outside number by the inside number. Qualitative uses approved test agents like irritant smoke, saccharine or isoamyl acetate to challenge the fit to see if the wearer can detect the agent.

Quantitative

PortaCount Quantitative Fit Testing System
Courtesy TSI, Inc.

Qualitative

Allegro Complete Smoke Fit Test Kit Photo
Courtesy Gempler's

Most practitioners prefer to test with a quantitative unit because you can see the different fits that are afforded with various manufacturers. Medium size half-face respirators can provide dramatically different fits on an individual. You can't determine this with qualitative testing. It is either yes or no.

User seal checks must be performed before *each* use to ensure a good fit.

A major point that is often confusing about respirators is the difference between a fit check and a seal check. The former is the qualitative and quantitative tests that we just described. They determine that a specific manufacturer and size respirator is right for you. That is a fit check. After we know what respirator fits you, it is important that you perform seal checks each time to be sure the respirator is seated properly. A seal check is done by covering the material with your hands and seeing if the respirator buckles in during inhalation and bubbles out slightly during exhalation. A seal check is easier to perform with an elastomeric respirator.

Air purifying respirators filter out dusts and vapors.

- Must have the correct color-coded cartridge
- Must be NIOSH-approved

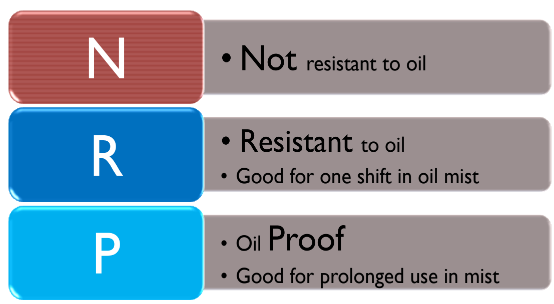
What type of filter is needed for nanoparticles?

Color	Type
Magenta, purple	High Efficiency Particulate Air (HEPA)
Black	Organic vapors only
Yellow	Organic vapors and acid gases

Color-coding is standardized for all manufacturers.

Particulate filters are classified based on resistance to oil.

NIOSH researchers noted that oil, like that found in the oil mists of factories where metal working equipment is constantly lubricated, was significantly damaging the filtration medium for particulate respirators without causing noticeable breathing resistance. Consequently, they established a new classification system under 42 CFR 84 that set up 3 classifications for particulate respirators.



Particulate filters are further classified based on efficiency.

95 percent efficient is designated 95.

99 percent is designated 99.

99.97 is designated 100 (this is the definition of HEPA).

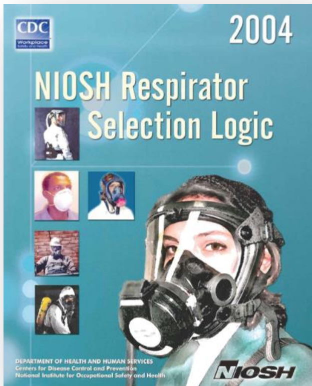
This gives 9 categories of particulate respirators.

N	R	P
100	100	100
99	99	99
95	95	95

Acceptable for nanomaterial work, unless oil is present

This is not an attempt to make things complicated, but to provide options depending on the severity of the hazards. N media, which is not resistant to oil, should be fine for most work that includes exposures to nanoparticles because no appreciable oil mist is generated.

NIOSH has developed a selection logic that can be applied to nanoparticles



http://www.cdc.gov/niosh/docs/2005-100

OSHA has added APFs to its respirator regulation that *generally* match the NIOSH Logic 1910.134(d)(3)(i)(A)

Table I: Assigned Protection Factors[5]

Type of Respirator[1, 2]	Quarter mask	Half mask	Full facepiece	Helmet/Hood	Loose-fitting facepiece
1. Air-Purifying Respirator	5	10[3]	50	—	—
2. Powered Air-Purifying Respirator (PAPR)	—	50	1,000	25/1,000[4]	25
3. Supplied-Air Respirator (SAR) or Airline Respirator					
• Demand mode	—	10	50	—	—
• Continuous flow mode	—	50	1,000	25/1,000[4]	25
• Pressure-demand or other positive-pressure mode	—	50	1,000	—	—
4. Self-Contained Breathing Apparatus (SCBA)					
• Demand mode	—	10	50	50	—
• Pressure-demand or other positive-pressure mode (e.g., open/closed circuit)	—	—	10,000	10,000	—

OSHA requires the employer to select a respirator that maintains exposure at or below the Maximum Use Concentrations (MUC)

MUC = APF X PEL

"When no OSHA exposure limit is available…an employer must determine an MUC on the basis of relevant available information and informed professional judgment."

Applying the MUC: Class Exercise

Where must exposures be measured?

An airborne concentration of 185 ug/m^3 is measured as an 8-hr. TWA for a CNT furnace cleanout. Is this an overexposure if the worker wore a full-face air-purifying respirator with P-100 cartridges? What OEL did you use?

What about for a half-face respirator with P-100 cartridges?

Physical stressors need to be considered.

- Lack of physical fitness
- Age
- Dehydration
- Obesity
- Work Rate
- Ambient Temperature

It is important to consider physical stressors before allowing a worker to wear a respirator or a suit.

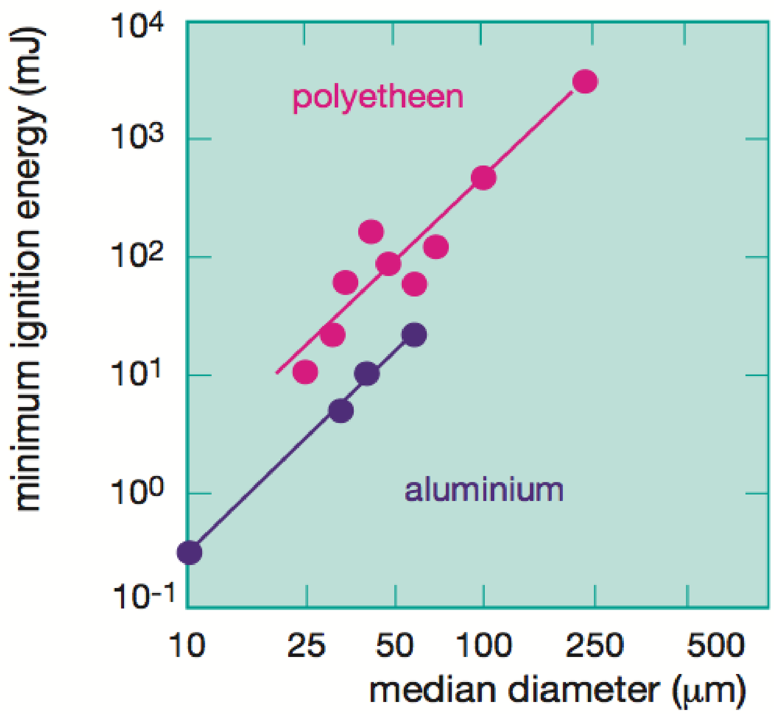
Topic 6: Fire hazards of nanoparticles

The British Health and Safety Lab, part of the Health and Safety Executive, reviewed the literature in 2004 and concluded:

- An increasing range of materials that are capable of producing explosive dust clouds are being produced as nanopowders. At the same time new uses of nanopowders are further adding to the demand for these powders. While some of these nanopowders are only being produced in very small quantities at present, and may continue to be for the foreseeable future, the production of others is likely to increase significantly over the next few years.
- There is a growing concern over the impact the increased use of nanopowders and other nanomaterials will have on health and safety and the environment. These concerns are almost exclusively centered on the potential toxic effects of nanomaterials. The potential explosion hazards of nanopowders have not been addressed.

- There is a considerable body of knowledge on the explosion characteristics of micronscale powders (particle sizes ranging from about 10 to 500 **m**m). A literature search has found no data for nanopowders (particle sizes of 1 to 100 nm). It is considered that the extrapolation of the data for larger particles to the nano-size range cannot be carried out with any degree of confidence, due to marked change in the chemical and physical properties of particles below sizes of about 100 nm.
- It is recommended that the explosion characteristics of a representative range of nanopowders be determined using the standard apparatus and procedures already employed for assessing dust explosion hazards. Comparison with data for micron-scale powders of the same materials will allow knowledge of particle size effects to be extended into the nanosize range.

Minimum ignition energy drops steeply as particle size drops



Netherlands Organization for Applied Scientific Research

Module 5: Risk and Hazard communication

Lesson Overview

The purpose of this module is to provide nanoworkers with a basis to compare the risks of nanoparticles against other, more familiar risks and to explain the concept of control banding as an alternative to normal industrial hygiene measurements.

These topics will be covered:

1. What is risk?
2. NanoRisk Framework
3. Control Banding
4. Communicating Hazards to Workers

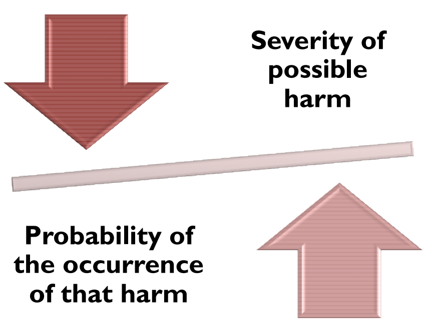
Learning Objectives

At the end of this module you will be able to:

- Explain the difference between risk and hazard
- Explain the standard definition of risk in terms of probability and severity
- Explain control banding and give a nanoparticle example
- Describe the limitations of the current hazard communication efforts around engineered nanoparticles

Topic 1: What is risk?

Risk is a function of



Who's more uncomfortable flying than driving?

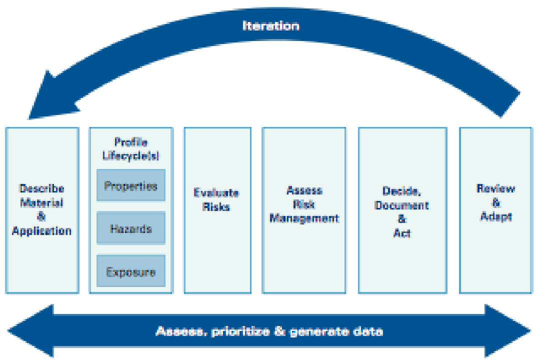
- The likelihood of dying on a jet flight is 1 in 8,000,000.
- This is flying around the clock for more than 438 years before a fatal crash. (FAA, 1998)
- Odds of dying in car crash: 1/84 (NSC, 2007)

Odds of Dying, 2003 National Safety Council

Event	# of Deaths	One-year Odds	Lifetime Odds
Lightning	47	6,188,298	79,746
Animal rider or animal-drawn vehicle	101	2,879,703	37,110
Venomous spiders	8	36,356,251	468,508

Topic 2: NanoRisk Framework

The EDF-DuPont Nano Risk Framework is highly regarded.



Step 1: Describe material and application

Step 2: Profile lifecycles

Step 3: Evaluate risks

Step 4: Assess risk management

Step 5: Decide, document and act

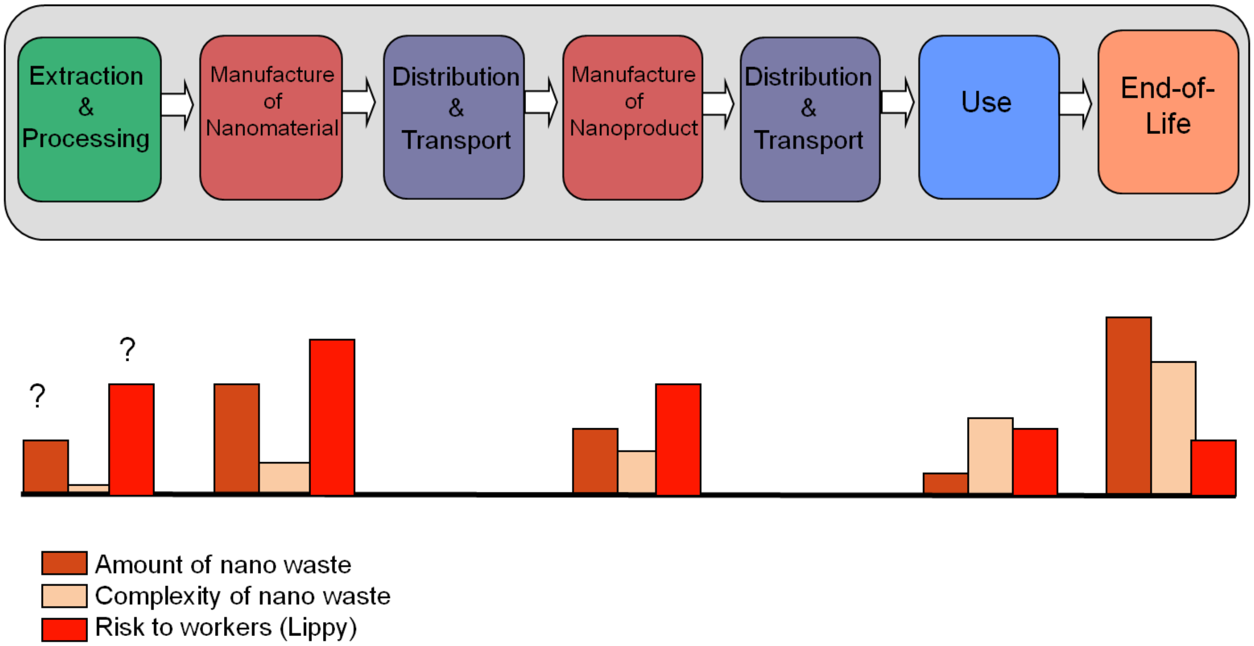
Step 6: Review and adapt

Through these six steps, the framework seeks to guide a process for risk evaluation and management that is practical, comprehensive, transparent, and flexible. The Framework, and case studies demonstrating its implementation on a variety of nanomaterials and applications, are available for download in PDF form.

Nano Risk Framework case studies are available on the web at **http://nanoriskframework.org**:

- TiO_2 light stabilizer by Dupont
- Carbon nanotubes
- Nano FeO

The entire life cycle needs to be considered



Graphic courtesy David Rejeski, Wilson Center for Scholars

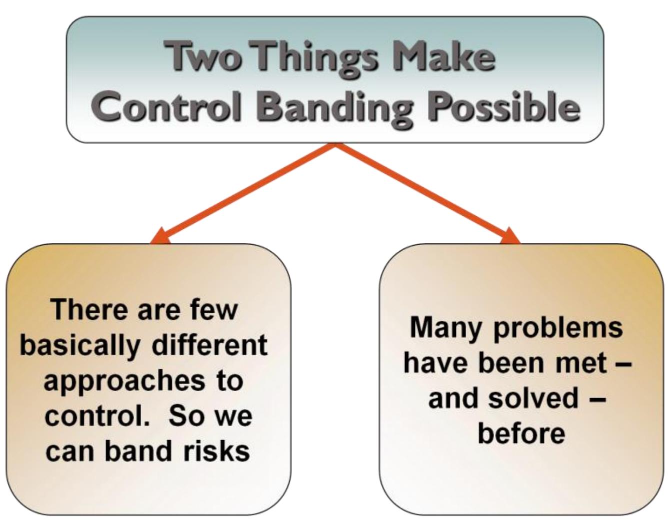
This is a graphic created by David Rejeski of the Wilson Center for Scholars to depict the entire life cycle of a nanoproduct and to consider the amount and complexity of the waste throughout that life cycle. Bruce Lippy attempted to estimate the degree of risks to working during the life cycle.

Topic 3: Control Banding

Control banding is a *qualitative* administrative approach that defines risks and sets controls.

Risk = probability X severity

Two Things Make Control Banding Possible.



Source: Paul Evans, 3rd International Control Banding Workshop, South Africa, September 2005

Control Banding has been used for years in the pharmaceutical industry

Band No.	Range of exposure concentrations	Hazard group	Control
1	>1 to 10 mg/m^3 dust >50 to 500 ppm vapor	Skin and eye irritants	Use good industrial hygiene practice and general ventilation
2	>0.1 to 1 mg/m^3 dust >5 to 50 ppm vapor	Harmful on single exposure	Use local exhaust ventilation
3	>0.01 to 0.1 mg/m^3 dust >0.5 to 5 ppm vapor	Severely irritating and corrosive	Enclose the process
4	<0.01 mg/ m^3 dust <0.5 ppm vapor	Very toxic on single exposure, reproductive hazard, sensitizer*	Seek expert advice

*Exposure to any concentration of a sensitizer requires expert advice

NIOSH provides the following excellent explanation of control banding.

The occupational exposure limit (OEL) is the marker that shows the level of control needed for a chemical. Repeated daily exposure by inhaling a chemical at an airborne concentration below its OEL is unlikely to lead to harm in most workers. However, many thousands of chemicals are in use, and it is not possible to have an OEL for every chemical, chemical mixture, fume, or emission. Nonetheless, it is possible to determine the broad hazard group to which a chemical belongs and on that basis to determine the necessary level of control, or control band.

The concept of control banding was developed in the late 1980s by occupational health experts in the pharmaceutical industry. This industry uses large numbers of new chemical compounds with few toxicity data. The experts reasoned that such compounds could be classified into bands by their toxicity and by their need for restriction of exposure. Each band was aligned with a control scheme.

Control banding is not appropriate for many situations, including "hot" processes, open spray applications, gases, and pesticides. These situations involve more complex exposures requiring additional considerations that are not yet fully addressed by current control banding strategies. In addition, control banding does not yet cover safety hazards, environmental issues, or ergonomic issues. Researchers are exploring ways to integrate these additional workplace issues into the control banding concept.

Control banding was proposed for nanomaterials in 2007 (Maynard)

A. D. Maynard

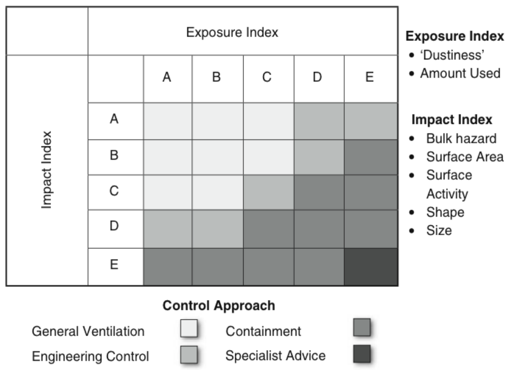


Fig. 7. Conceptual interpretation of how a control-banding type of approach might be applied to airborne engineered nanomaterials.

Maynard, AD. (2007) Nanotechnology: the next big thing, or much ado about nothing? Ann Occ Hyg 51(1); 1-12.

Lawrence Livermore developed a Control Banding Nanotool (Sam Paik, LLNL)

Probability

Severity		Extremely Unlikely (0-25)	Less Likely (26-50)	Likely (51-75)	Probable (76-100)
	Very High (76-100)	RL 3	RL 3	RL 4	RL 4
	High (51-75)	RL 2	RL 2	RL 3	RL 4
	Medium (26-50)	RL 1	RL 1	RL 2	RL 3
	Low (0-25)	RL 1	RL 1	RL 1	RL 2

RL 1: General Ventilation
RL 2: Fume hoods or local exhaust ventilation
RL 3: Containment
RL 4: Seek specialist advice

Courtesy Sam Paik and Lawrence Livermore National Laboratory

The Nanotool sets Severity Factors.

Nanomaterial: 70% of Severity Score.

- Surface Chemistry (10 pts)
- Particle Shape (10 pts)
- Particle Diameter (10 pts)
- Solubility (10 pts)
- Carcinogenicity (6 pts)
- Reproductive Toxicity (6 pts)
- Mutagenicity (6 pts)
- Dermal Toxicity (6 pts)
- Asthmagen (6 pts)

Factors for the parent material get 30% of severity score.

- Occupational Exposure Limit (10 pts)
- Carcinogenicity (4 pts)
- Reproductive Toxicity (4 pts)
- Mutagenicity (4 pts)
- Dermal Toxicity (4 pts)
- Asthmagen (4 pts)

(Maximum points indicated in parentheses)

This is an interesting approach because there will invariably be more data on the "macro" sized version of the material, e.g. carbon black or graphite rather than CNT, but the data are only given 30% of the weight because of the chance that the nano-sized version is more toxic.

Nanotool uses probability factors, too.

- Estimated amount of material used (25 pts)
- Dustiness/mistiness (30 pts)
- Number of employees with similar exposure (15 pts)
- Frequency of operation (15 pts)
- Duration of operation (15 pts)

Nanotool results were comparable to judgment of professionals.
36 operations at LLNL

- For 21 activities, CB Nanotool recommendation was equivalent to existing controls
- For 9 activities, CB Nanotool recommended higher level of control than existing controls
- For 6 activities, CB Nanotool recommended lower level of control than existing controls

CB Nanotool as LLNL Policy

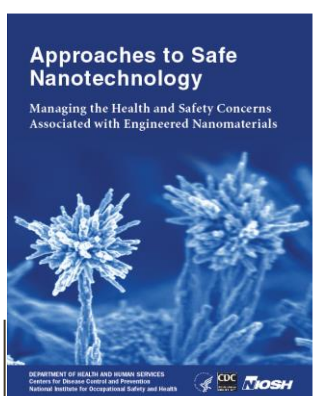
- Overall (30 out of 36), CB Nanotool recommendation was equal to or more conservative than IH expert opinions
- LLNL decided to make CB Nanotool recommendation a requirement
- CB Nanotool is an essential part of LLNL's Nanotechnology Safety Program

Let's use the Nanotool in an exercise

The Nanotool is on an Excel spreadsheet. Let's work an example.

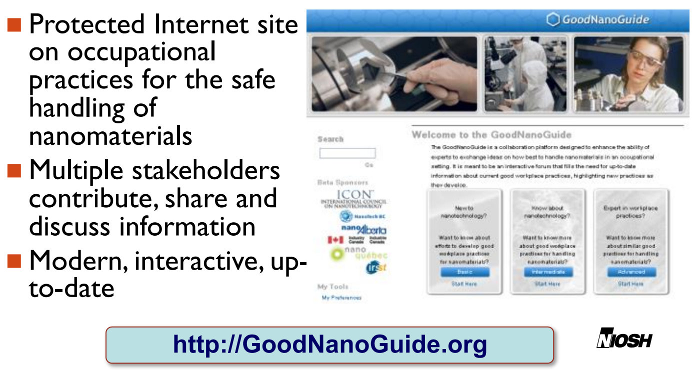
Topic 4: Communicating hazards to workers

NIOSH has excellent resources

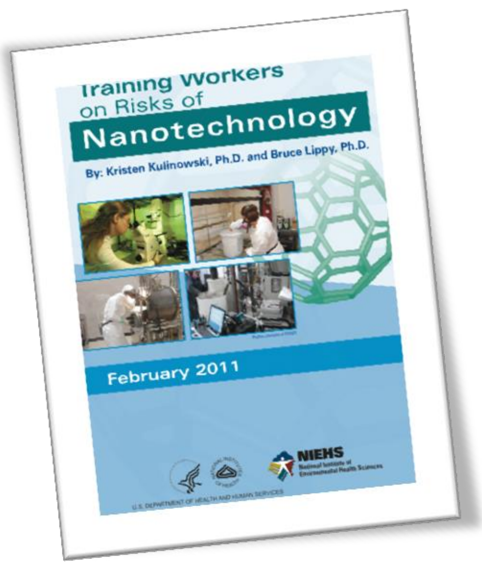


www.cdc.gov/niosh/topics/nanotech

The GoodNanoGuide is a tremendous resource.



This NIEHS guidance on training workers is available at: http://is.gd/NIEHSnano



Unfortunately, we haven't been doing a great job communicating the hazards of *standard* industrial chemicals.

Hazard Communication: A Review of the Science Underpinning the Art of Communication for Health and Safety, Sattler, Lippy & Jordan, May, 1997. Available at OSHA's website: https://www.osha.gov

1997 review of Hazcom literature for OSHA was the only one for a decade.

- University of Maryland contract with OSHA.
- Accuracy of technical information was a problem.
- Most studies were based on reported preferences, not behaviors.
- Populations studied were students not workers.

One expert panel review established that only 11% of the MSDSs were accurate in all of the following four areas: health effects, first aid, personal protective equipment, and exposure limits. Further, the health effects data on the MSDSs frequently are incomplete and the chronic data are often incorrect or less complete than the acute data.

Kolp, P.W.; Williams, P.L.; and Burtan, R.C. 1995. Assessment of the Accuracy of Material Safety Data Sheets. Journal of the American Industrial Hygiene Association 56:178-183.

Comprehensibility of MSDSs was not good.

On average, literate workers only understood about 60% of the health and safety information on sample MSDSs in three different comprehensibility studies. This percentage was remarkably similar across three studies (Printing Industry of America, 1990, Kolp et al. 1993, Campbell, 1997.)

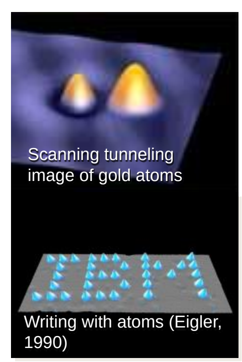
A newer review of the literature was completed in 2008. (Nicol, A.M. et al. (2008), Accuracy, comprehensibility, and use of material safety data sheets: A review. Am. J. Ind Medicine)

Nicol et al. reviewed the peer-reviewed scientific literature regarding the accuracy, comprehensibility and use of MSDSs in the workplace. Of the 280 unique articles retrieved, 24 fit their review criteria. Eligible articles included a range of methodologies: laboratory analyses, site audits, surveys and qualitative inquiry. Articles were grouped into three main topic categories: accuracy and completeness, awareness and use, and comprehensibility. Accuracy and completeness were found to be relatively poor, with the majority of studies presenting evidence that the MSDSs under review did not contain information on all the chemicals present, including those known to be serious sensitizers or carcinogens. Poor presentation and complex language were consistently associated with low comprehensibility among workers. Awareness and use of MSDSs was suboptimal in workplaces where these factors were studied.

Nicol et al. concluded:

“While MSDSs are still considered to be a mainstay of worker health and safety…there are significant problems with their accuracy and completeness. As such, they may be failing workers as a prevention tool.”

Sheer number of chemicals will become truly daunting.



Top image is a scanning tunneling microscope (STM) false-color image of two gold atoms on an insulating NaCl film surface. The atom on the left-hand side has been intentionally transferred from its neutral state into a negatively charged ion by means of STM manipulation.

Writing with atoms. D.M. Eigler, E.K. Schweizer. Positioning single atoms with a scanning tunneling microscope. *Nature 344, 524-526 (1990).*

- OSHA has 40 year-old standards for 600 chemicals. The Bush administration wrote only one standard in 8 years – hexavalent chrome - and it took a Congressional mandate to get them to do it.
- The Chemical Abstract Service reported **62,526,489** chemical sequences on their website (2/23/11).
- 112 known elements
- 10^{200} to 10^{900} distinct nanoscale particle possibilities (according to one estimate).

Is it too soon to talk Hazcom for Nano?

There are over 1,300 consumer products listed on Project on Emerging Nanotechnologies website. Workers are producing these items. Shouldn't we be serious about hazard communication?

Wilson Center has 1317 products, produced by companies located in 30 countries (03-10-11)

This is the most complete database of consumer products. The criterion they used:

1) Readily purchased by consumers

2) Identified as nano-based by the manufacturer OR another source, and

3) The nano-based claims for the product *appear* reasonable.

Example MSDS for Multi-walled Carbon Nanotubes, Section 11 Toxicology

This language is from an actual MSDS: "May be harmful if absorbed through the skin or swallowed. To the best of our knowledge the chemical, physical, and toxicological properties have not been thoroughly investigated."

How useful is this language?

Lippy Group reviewed NIOSH's collection of nano MSDSs.

- N = 49 "Improving" MSDSs
- Reviewed all of the MSDSs
- 33% did NOT identify the nano component
- 52% did NOT have any cautionary language

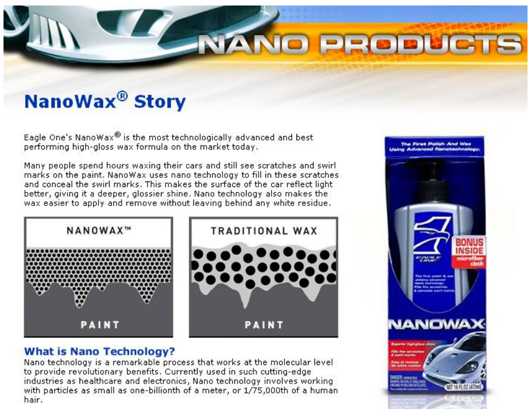
NIOSH just completed a review of SDSs
(C. Crawford, L. Hodson, and C. Geraci, 2011, AIHce Poster)

- A total of 29 updated SDSs were reviewed from 22 manufacturers of engineered nanomaterials.
- The review revealed that only 5 had improved compared to the 2007-08 versions.
  - 21 of the 29 (72%) were ranked as not having any significant improvement.
  - 3 of the 29 (10%) had not changed anything (including the date) since the original NIOSH study.
  - Lack of recent toxicological data was main deficiency

NIOSH looked at 26 new MSDSs from 19 manufacturers

- 15 (58%) contained OELs for the bulk material without providing guidance that the OEL may not be protective for the nanoscale material.
- *18 (69%) of the 26 new SDSs* were classified as *in need of serious improvement* and
- None were classified as good

Example MSDS: NanoWax



The finer particles apparently fill in scratches and swirl marks in the paint and reflect light better.

NanoWax MSDS
Section 8: Exposure Controls/PPE

WAX EMULSION: No exposure limits established (NLE)

ALIPHATIC PETROLEUM DISTILLATES (64741-66-8): NLE

ALUMINUM SILICATE (66402-68-4): NLE

POLY(DIMETHYLSILOXANE) (63148-62-9): NLE

ALKYL QUATERNARY AMMONIUM BENTONITE (68953-58-2) : NLE

TETRAGLYCERYL MONOOLEATE (9007-48-1): NLE

GLYCOL (107-21-1)

OSHA PEL 50 ppm - Ceiling

ACGIH TLV 100 mg/m3 - Ceiling as an aerosol

There is no indication which component is nano-sized. Aluminum silicate is a likely candidate.

Lippy Group MSDS Review
Use of Occupational Exposure Limits

- 62% used OSHA Permissible Exposure Limits or ACGIH TLVs for “macro” sized material
- 32% percent indicated nothing

- Only 6% used conditional language about using PELs/TLVs

MSDS for Carbon Nanotube

Section 1 Product Identification

Chemical Name:	Carbon Fullerene
Formula:	Carbon
Chemical Family:	Synthetic Graphite
Synonyms:	Carbon Nanotubes
CAS Number:	7782-42-5 (Graphite)

"Nuisance" dust standard for synthetic graphite: 15 mg/m^3

Section 2 Composition and Information on Ingredients

Component	%	OSHA/PEL	ACGIH/TLV
Synthetic graphite	Up to 100%	15 mg/m^3 (total dust) 5 mg/m^3 (respirable fraction)	2 mg/m^3 TWA

"The MSDSs for carbon nanotubes treats these substances as graphite…but carbon nanotubes are as similar to pencil lead as the soot on my barbeque grill at home is to diamonds."

Andrew Maynard, University of Michigan Risk Science Center

This MSDS for quantum dots of lead sulfide focuses on toluene

Section 1 - Chemical Product

Product Family #:	PbS Core EviDots
Substance:	Core EviDots packed in Toluene
Trade Names/Synonyms:	Core EviDots
Chemical Family:	Matrix: aromatic hydrocarbon Nanocrystal: IV-VI semiconductor compound

Section 2 - Composition, Information on Ingredients

Component	CAS#	EC#	% By Weight
Toluene	108-88-3	203-625-9	~ 99
Lead Sulfide (as nanocrystal compound)	1314-87-0	215-246-6	< 1

Exposure limit is for toluene, with nothing about PbS dots

Section 8 - Engineering Controls & Personal Protective Equipment

Exposure Limits	
Toluene	200ppm OSHA TWA PEL 300ppm ceiling OSHA 50ppm ACGIH TWA (skin) 100ppm (375 mg/m3) NIOSH TWA 10hour 190mg/m3 DFG MAK 50ppm (191 mg/m3) UK OES TWA

Ventilation was recommended on 77% of MSDSs, but details are wrong.

- 24% made specific face velocity recommendations
- ALL of those recommended “at least 100 fpm”
- NIOSH has recommended lower flow rates to avoid turbulence that can release the buoyant particles.

Flow Sciences, Inc.

Nano language suggested by Dan Levine, Hazcom Expert
(PSS, 9-15-2006)

“Established exposure values do not address the small size of particles found in this product and may not provide adequate protection against occupational exposures.”

PSS
Product Safety Solutions

Exercise:

Examine the MSDS you are given and determine whether it contains the following:

1. Indication of which component is nanoscale
2. Cautionary language on the use of the product due to its nanoscale component
3. PEL or TLV. Does this number refer to the nanoscale component, the non-nanoscale form of the nanoscale component or other components altogether?
4. Recommendations for personal protective equipment
5. Recommendations for engineering controls
6. Identification of safety concerns such as flammability or explosivity

Module 6: Regulations and Standards Relevant to Nanomaterial Workplaces

Lesson Overview

The purpose of this module is to provide workers with introductory information about OSHA and other standards and regulations relevant for nanomaterial workplaces.

These topics will be covered:

1. Your rights under the Occupational Safety and Health Act (OSH Act)
2. Relevant statutes and recent actions taken by EPA
3. Regulatory activity at the State and Local Levels
4. Standards developed for nanomaterial handling

Learning Objectives

At the end of this module you will be able to

- State your rights under the OSH Act
- Articulate which OSHA standards apply to nanomaterial workplaces
- Articulate other regulations and standards that are applicable to nanomaterial workplaces

Topic 1: Your rights under the Occupational Safety and Health Act (OSH Act)

History of OSHA

- OSHA stands for the Occupational Safety and Health Administration, an agency of the U.S. Department of Labor
- OSHA's responsibility is worker safety and health protection

- On December 29, 1970, President Nixon signed the OSH Act
- This Act created OSHA, the agency, which formally came into being on April 28, 1971

Adapted from a presentation of the Directorate of Training and Education, OSHA Training Institute

Introduction_to_OSHA_presentation.ppt available at http://www.osha.gov/dte/outreach/construction_generalindustry/teachingaids.html

Applicable OSHA Standards

Occupational Safety and Health Act of 1970 (29 U.S.C. 654)

- *General Duty Clause Section* 5(a)(1) requires employers to “furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees.”
- Section 5(a)(2) requires employers to "comply with occupational safety and health standards" promulgated under this Act.

The OSH Act provides a *general* right of protection for all regulated workplaces even where no specific standards have been published.

What Rights Do You Have Under OSHA?

You have the right to:

- A safe and healthful workplace
- Know about hazardous chemicals
- Information about injuries and illnesses in your workplace
- Complain or request hazard correction from employer
- Training
- Hazard exposure and medical records
- File a complaint with OSHA
- Participate in an OSHA inspection
- Be free from retaliation for exercising safety and health rights

Adapted from a presentation of the Directorate of Training and Education, OSHA Training Institute,

Introduction_to_OSHA_presentation.ppt available at http://www.osha.gov/dte/outreach/construction_generalindustry/teachingaids.html

Who is covered?

Most employees in the nation come under OSHA's jurisdiction. OSHA covers private sector employers and employees in all 50 states, the District of Columbia, and other U.S. jurisdictions either directly through Federal OSHA or through an OSHA-approved state program. State-run health and safety programs must be at least as effective as the Federal OSHA program.

State and Local Government Workers. Employees who work for state and local governments are not covered by Federal OSHA, but have OSH Act protections if they work in a state that has an OSHA-approved state program. Four additional states and one U.S. territory have OSHA approved plans that cover public sector employees only: Connecticut, Illinois, New Jersey, New York, and the Virgin Islands. Private sector workers in these four states and the Virgin Islands are covered by Federal OSHA.

Federal Government Workers Federal agencies must have a safety and health program that meet the same standards as private employers. Although OSHA does not fine federal agencies, it does monitor federal agencies and responds to workers' complaints. The United States Postal Service (USPS) is covered by OSHA.

Who is not covered by the OSH Act:

- The self-employed;

- Immediate family members of farm employers that do not employ outside employees; and
- Workers who are protected by another Federal agency (for example, the Mine Safety and Health Administration, the Federal Aviation Administration, the Coast Guard).

States with approved State Plans

- Alaska
- Arizona
- California
- Connecticut *
- Hawaii
- Illinois
- Indiana
- Iowa
- Kentucky
- Maryland
- Michigan
- Minnesota
- Nevada
- New Jersey *
- New Mexico
- New York
- North Carolina
- Oregon
- Puerto Rico
- South Carolina
- Tennessee
- Utah
- Vermont
- Virgin Islands *
- Virginia
- Washington
- Wyoming

Twenty-four states, Puerto Rico and the Virgin Islands have OSHA-approved State Plans and have adopted their own standards and enforcement policies. For the most part, these States adopt standards that are identical to Federal OSHA. However, some States have adopted different standards applicable to this topic or may have different enforcement policies.

*These plans cover public sector (State & local government) employment only.

Group Activity: Is This Worker Protected by OSHA? Mark your answer below:

Covered by OSHA?		Worker
YES	NO	1. Harry Adams, a miner at Below Ground Inc.
YES	NO	2. Juan Ramírez, one of 3 employees of ABC landscaping.
YES	NO	3. Taylor Ostrowski, an accountant in business for herself.
YES	NO	4. Rob LaFollette, one of 10 carpenters working for Woody, Inc.

Credit: Directorate of Training and Education, OSHA Training Institute, Introduction_to_OSHA_presentation.ppt available at http://www.osha.gov/dte/outreach/construction_generalindustry/teachingaids.html

Your Right to Know about Hazardous Chemicals

Employers must have a written, complete hazard communication program that includes information on container labeling, Material Safety Data Sheets (MSDSs), and worker training. The training must include the physical and health hazards of the chemicals and how workers can protect themselves; including specific procedures the employer has implemented to protect workers, such as work practices, emergency procedures, and personal protective equipment.

Adapted from a presentation of the Directorate of Training and Education, OSHA Training Institute, Introduction_to_OSHA_presentation.ppt available at http://www.osha.gov/dte/outreach/construction_generalindustry/teachingaids.html

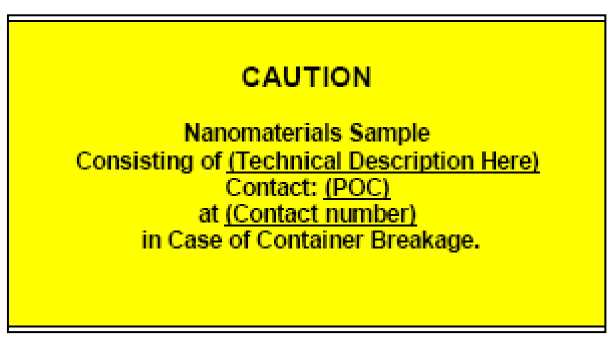
OSHA-Identified Nanomaterial Standards

The following are examples of standards that may be applicable in situations where employees are exposed to nanomaterials. As you can see none of these is specific to nanomaterials but all are applicable to workplaces where hazardous substances may be present. The subject-specific standards may be applicable to nanoscale forms of the materials covered in the standard. E.g., 1910.1027, Cadmium, may apply where cadmium selenide quantum dots (nanoparticles) are handled.

- 1904, Recording and reporting occupational injuries and illness
- 1910.132, Personal protective equipment, general requirement
- 1910.133, Eye and face protection
- 1910.134, Respiratory protection
- 1910.138, Hand protection
- 1910.141, Sanitation
- 1910.1200, Hazard communication
- 1910.1450, Occupational exposure to hazardous chemicals in laboratories
- Certain substance-specific standards (e.g., 1910.1027, Cadmium)

Container Labels

Best practice would argue that containers should be labeled to indicate that the contents contain nanomaterials, but there is no OSHA standard for nanomaterial container labels. This suggested example would alert others to the presence of a substance that may require special handling or have unknown toxicity.



- Technical Description = chemical substance e.g., carbon nanotubes, nano-titania (rutile), poly(ethylene glycol)-coated gold-silica nanoshells
- POC = Point of Contact
- Contact Number = Telephone number of POC

This sample label was created by the Center for High-Rate Nanomanufacturing in its document, “Interim Best Practices for Working with Nanoparticles”

Topic 2: The U.S. Environmental Protection Agency

Environmental Protection Agency

Statute	Acronym	Topic
Toxic Substances Control Act	TSCA	chemical substances
Federal Insecticide, Fungicide, and Rodenticide Act	FIFRA	pesticides
Clean Air Act	CAA	air pollutants
Clean Water Act	CWA	discharge of pollutants into the navigable waters
Comprehensive Environmental Response, Compensation and Liability Act	CERCLA	uncontrolled releases of hazardous materials
Resource Conservation and Recovery Act	RCRA	solid or hazardous waste

EPA has invested the most time and effort to date in understanding the impact of nanomaterials on the agency’s enforcement of the Toxic Substances Control Act (TSCA, “tosca”) and the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA).

Under TSCA, EPA can require manufacturers, processors and importers of chemical substances to notify EPA prior to engaging in commercial activity. EPA can then impose mandatory reporting and testing requirements and can limit the production or use of those substances. TSCA has both testing and reporting requirements for toxic substances that may impact nanomaterial commerce.

Some Branches on TSCA Decision Tree

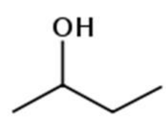
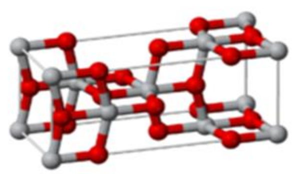
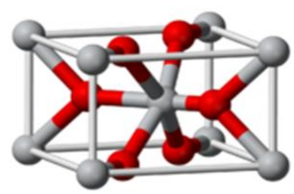
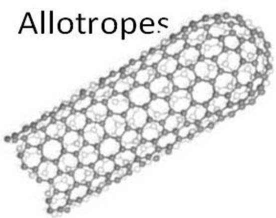
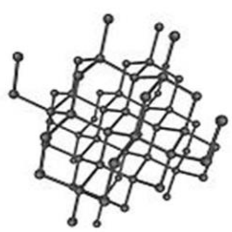
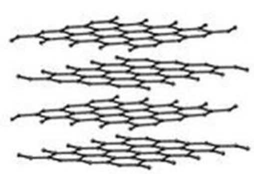
The TSCA regulatory process is complex and this is not meant to be an exhaustive compliance course. However, even cursory examination of the TSCA reporting criteria reveals that nanoscale materials are not explicitly accounted for. Each of these three questions reveals regulatory gaps through which nanoscale materials could fall.

Is it a chemical substance; i.e., does it have a particular molecular identity?

Is it already listed on the TSCA inventory in a non-nanoscale form?

Is it exempt because it is an intermediate, impurity, or produced in very low volume?

Substances EPA Recognizes as Distinct

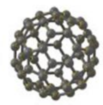
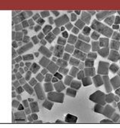
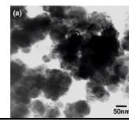
Feature	Example		EPA Verdict
Molecular formula	C_2H_6	C_3H_8	DIFFERENT
Isomers			DIFFERENT
Crystal Structures			DIFFERENT
Allotropes	 		DIFFERENT

Regarding the first two decision points, here are several examples of substances that bear similarity to one another but are considered by EPA to have distinct "particular molecular identities."

- Substances with different molecular formulas (ethane and propane)
- Isomers, or substances with the same molecular formula but a different way of bonding the atoms to each other (n-butanol and 2-butanol)
- Substances with the same molecular formula but different crystal structures (shown here are anatase and rutile titanium dioxide)

- Allotropes, or variants of a substance consisting of only one atom (note that the carbon nanotube on the left is considered to be a distinct substance from diamond and graphite, two other allotropes of carbon)

Substances Defined to be the Same

Feature	Example		EPA Verdict
Aggregates or particles of known substances			**SAME**
Nanoscale versions of known substances			**SAME**

"Although a nanoscale substance … differs in particle size and may differ in certain physical and/or chemical properties, EPA considers the two forms to be **the same chemical substance** because they have the same molecular identity."

What It Is | What It Does

Notice how the strict interpretation of the definition of "particular identity" results in nanoscale materials being considered the same as their conventional analogs.

- A single C_{60} molecule is considered the same as a nanoscale aggregate (or crystal) of buckyballs.
- A nanoscale titanium dioxide powder is considered the same as the relatively benign microscale form. [There is research that shows differential toxicity of these two forms.]

The quote is taken from a 2007 statement made by EPA clarifying its position that the size of the substance is not enough to override the strict interpretation of "molecular identity." Because microscale titanium dioxide is generally recognized as safe in many applications, including being used as a whitening agent in milkshakes, yogurt and toothpaste, the nanoscale form gets a pass because it has the same molecular identity.

In essence, this statement clarified EPA's approach as continuing to look at a nanoscale material on the basis of *What It Is* (chemical composition) rather than basing its regulatory decision-making on *What It Does* (i.e., its physical and chemical properties, toxicity, and environmental impacts).

Low-Volume Exemption (LVE)

Many nanoscale substances could qualify for an exemption from TSCA reporting and testing requirements if less than 10,000 kg/year are sold. Some nanoscale materials may be extremely active at very low concentrations as a result of their small size and large surface area-to-volume ratio. Therefore, the appropriateness of this exemption may need to be examined on a case-by-case basis.

Recent Actions taken by EPA (2010)

The strict 2007 interpretation of molecular identity is being challenged by EPA in light of the toxicity and environmental impact data. In three proposals released in Fall 2010, EPA signaled its intention to approach regulation of nanoscale materials under TSCA in a new way. Each proposal has been subject to criticism by industry as being unnecessarily burdensome and awaits final approval.

1. Designates any use of nanoscale substance as a Significant New Use, which would require 90-day pre-commerce notification (PROPOSED)
2. Requires companies to report production volume, methods of manufacture and processing, exposure and release information, and available health and safety data (PROPOSED)
3. Requires manufacturers to conduct testing for health effects, ecological effects, and environmental fate, as well as to provide material characterization data on certain multiwall carbon nanotubes, and nanoscale clays and alumina (PROPOSED)

IMPLICATIONS FOR WORKERS: The federal government's lead agency for regulating toxic substances has begun to scrutinize nanoscale materials more closely and is beginning to impose testing and reporting requirements that impact nanomaterial workplaces. In particular, EPA has indicated that the employer in workplaces that handle certain nanoscale materials, such as multiwall carbon nanotubes, must provide personal protective equipment and other appropriate engineering controls to safeguard the health and safety of its workers.

Requirements EPA Has Imposed

For certain multiwall carbon nanotubes

- Use gloves impervious to nanoscale particles and chemical protective clothing;
- Use a NIOSH–approved full-face respirator with an N -100 cartridge while exposed by inhalation in the work area; and
- Distribute the substance only to a person who agrees to follow the same restrictions.

Siloxane-modified silica nanoparticles

- Use with impervious gloves; and
- Use a NIOSH-approved respirator with an APF of at least 10

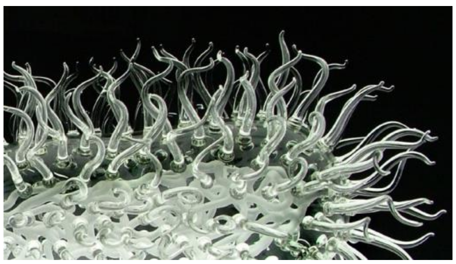
These respirators meet the requirements for handling siloxane-modified silica and alumina nanoparticles:

- Air-purifying, tight-fitting respirator equipped with N100 (If oil aerosols are absent);
- R100, or P100 filters (either half- or full-face);
- Powered air-purifying respirator equipped with a loose-fitting hood or helmet and High Efficiency Particulate Air (HEPA) filters;
- Powered air-purifying respirator equipped with a tight-fitting facepiece (either half- or full-face) and HEPA filters;
- Supplied-air respirator operated in pressure demand or continuous flow mode and equipped with a hood or helmet, or tight-fitting facepiece (either half- or full-face).

Sources: MWNT: Consent Order issued in regard to PMN Number P-08-0177; Siloxane modified silica nanoparticles: SNUR issues in regard to PMN Number P–05–673

Siloxane modified alumina nanoparticles: SNUR issues in regard to PMN Number P–05–687

Federal Insecticide, Fungicide and Rodenticide Act (FIFRA)



EPA requires a manufacturer to register a product as a pesticide if that product incorporates a substance intended to destroy pests, including microbes.

E. coli, http://www.lukejerram.com/

The other statute for which EPA has taken action on nanomaterials is the FIFRA (or pesticide act). In everyday language a pesticide is something that kills cockroaches, ants, mosquitoes and other nuisance pests. In addition to insects the word ‘pest’ in EPA jargon includes another class of ‘bugs’: microbes. Therefore, any product that claims to kill bacteria, viruses, fungi or other unwanted microbes is classified as a pesticide or pest control device by the EPA. A product that uses physical or mechanical means to control a pest is a pest control device (e.g., untreated flypaper and UV light disinfection systems) and does not require registration under FIFRA but if it uses a substance to control pests then it is a pesticide and must be registered if it makes a pesticidal claim.

Pesticidal Device or Pesticide?

Silver has been known to be a potent antimicrobial device for millennia. Silver is also highly toxic to many forms of animal life (though not as much to humans); therefore, EPA enforces limits on the release of silver into the natural environment.

Ionic silver (Ag^+) and nanosilver are being incorporated into an increasing number of household products and sporting goods to make them “germ-free.” These include food storage containers, socks and underwear, disinfectant spray products, toothpastes and others. The rise of silver use in consumer products has led to increased concerns over the release of silver in the environment.

Case Study:

The manufacturer of a new washing machine began marketing its products as superior to conventional machines on the basis that the silver ions released during the wash cycle would actively kill odor-causing bacteria. Clothes can be cleaned at lower water temperature, thereby saving energy, and with less detergent. Moreover, the company claimed that the silver residue left on the fabrics would extend the antibacterial action for up to one month post-wash.

In 2005 EPA made a decision to classify the washing machine as a pesticidal device due to the antibacterial claim made by the manufacturer. This permitted the machine to be sold without further regulation. Several waste water treatment plant operators joined together to petition EPA to reclassify the machine as a pesticide.

Exercise:

Why would waste water treatment plant operators care about silver washing machines?

What is the technical basis for the waste water treatment plant operators' petition?

What do you think EPA did in response to the petition?

Additional Facts:

- One source estimates the global production of nanosilver to be 500,000 kg per year.
- This real-life case was reported as the first case of federal regulation of a nanomaterial because the product had the word "nano" in its name and the manufacturer's marketing materials mentioned nanosilver as the active agent. In all likelihood these are simply garden variety silver ions released via electrolysis of a silver metal block.

Answers to Exercise

Why would waste water treatment plant operators care about silver washing machines?
Silver is a regulated component of treatment plant effluent. Plant operators are responsible to keep their effluents (liquid) and sludge (solid) releases within federal standards for a variety of toxic substances, including silver. Excess releases of silver from washing machine discharges could result in fines or increased costs to remove the silver.
Bonus: Waste treatment plants rely on microbes to digest raw sewage so excess silver could potentially disrupt or deactivate the bacterial workforce within the plant.

What is the technical basis for the waste water treatment plant operators' petition?
The plant owners argued that silver is a substance. Therefore the mechanism of action was not merely physical or mechanical.

What do you think EPA did in response to the petition?
In 2007 EPA reclassified the machine as a pesticide and requested information from the manufacturer about the potential impact of the machine on silver levels in the waste treatment system.

Other EPA Actions on NanoSilver

$208,000 Fine


Suit Filed;
Claim removed


$82,400 Fine

EPA has taken several other definitive actions against products of nanotechnology that make antimicrobial claims. Without exception the fines were a result of failing to register the products with the EPA prior to promoting them with the antimicrobial claims.

Left: EPA fines ATEN Technology, Inc. $208,000 for failure to register antimicrobial computer products including computer-mouse keyboard combinations that claimed to be "germ-free" [Feb 2008]

Center: EPA files suit against VF Corporation (owner of North Face brand) for failing to register dozens of products containing the AgION antimicrobial foot bed liner [Sept 2009]

Right: EPA fines Kinetic Solutions Inc for failing to register its Rabbit Air air purifiers which tout the use of "Nano-Silver Sterilization - Features a Nano-Silver pre-filter to help kill airborne bacteria, mold and viruses." [Dec 2010]

Bottom line: If you make an antimicrobial claim, regardless of whether there's **nanotechnology** involved or not, you'd better register your product with the EPA.

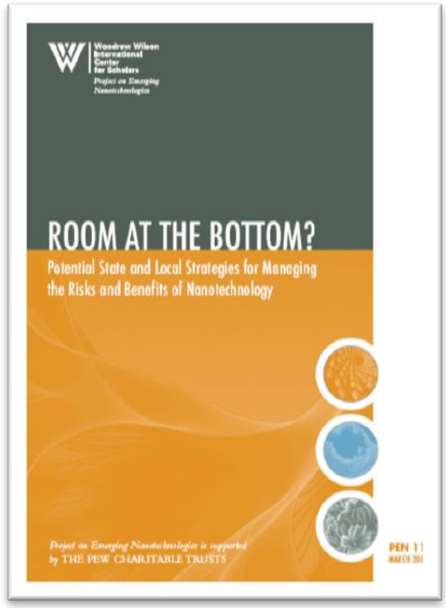
Topic 3: Regulatory Activity at the State and Local Levels

States Begin to Fill Regulatory Vacuum

- States are "laboratories of democracy"
- State regulations may be more stringent than federal

- State regulations can fill gaps where federal law is silent
- Areas where States may act (have acted)
- Disclosure laws
- Adopt standards as law
- Engage stakeholders to a greater degree
- Establish regional initiatives

Full report at http://www.nanotechproject.org/process/assets/files/6112/pen11_keiner.pdf



City of Berkeley Issues Notification Rule

In December 2006, the Berkeley City Council passed an ordinance requiring that "All facilities that manufacture or use manufactured nanoparticles shall submit a separate written disclosure of the current toxicology of the materials reported, to the extent known, and how the facility will safely handle, monitor, contain, dispose, track inventory, prevent releases and mitigate such materials."

This was reported as the nation's only local regulation of nanotechnology. Mayor Tom Bates said, "This actually is a groundbreaking ordinance. The EPA and the federal government have basically not looked at nano particles." (Source: FoxNews.com, December 13, 2006.)

AMENDING BERKELEY MUNICIPAL CODE (BMC) SECTION 15.12.040 TO ADD SUBSECTION I AND AMENDING BMC SECTION 15.12.050 TO ADD SUBSECTION C.7, REGARDING MANUFACTURED NANOPARTICLE HEALTH AND SAFETY DISCLOSURE

BE IT ORDAINED by the Council of the City of Berkeley as follows:

Section 1. That Berkeley Municipal Code Section 15.12.040 is amended to add Subsection I to read as follows:

15.12.040 Filing of disclosure information.

I. All facilities that manufacture or use manufactured nanoparticles shall submit a separate written disclosure of the current toxicology of the materials reported, to the extent known, and how the facility will safely handle, monitor, contain, dispose, track inventory, prevent releases and mitigate such materials.

Section 2. That Berkeley Municipal Code Section 15.12.050 is amended to add Subsection C.7 to read as follows:

15.12.050 Quantities requiring disclosure.

C. The following disclosure requirements shall apply in addition to those in subsections A and B of this section:

7. All manufactured nanoparticles, defined as a particle with one axis less than 100 nanometers in length, shall be reported in the disclosure plan.

State of California Data Call-Ins

2006

- Assembly Bill (AB) 289 passed; amends *Health and Safety Code*, Chapter 699, sections 57018-57020
  - Intended to make relevant information on the fate and transport, analysis, and other information on chemicals more available, and to fill information gaps where necessary

2009

- Call-In for CNTs Issued
  - Analytical test methods
  - Fate and transport in the environment
  - Other relevant information

2010

- Deadline for CNT reporting
  - 22 companies and universities responded
- New call-in issued to 49 companies and universities for nano silver, nano zero valent iron, nano TiO_2, nano CeO_2, nano ZnO, quantum dots
  - Analytical test methods in environmental matrices

http://www.dtsc.ca.gov/technologydevelopment/nanotechnology/index.cfm
http://www.dtsc.ca.gov/TechnologyDevelopment/Nanotechnology/CNTcallin.cfm

Topic 4: Standards Developed for Nanomaterial Handling

Voluntary Consensus Standards

Standard developing organizations produce standards via a consensus process. The standards are not binding but can be incorporated into regulations or codes, becoming de facto regulations. Standards often precede the development of regulation because the development process is more rapid. A standard can be developed in as little as 6 months if enough volunteers are willing to write it and guide it through the process. The standards process can serve as a stop-gap attempt at self-regulation in fast-moving or emerging areas where regulation is not set.

Other Standards: ISO and ASTM

The two most relevant voluntary consensus standards for occupational practice were published by ASTM International and ISO-The International Organization for Standardization

ASTM E2535 focuses on ways to minimize exposure to nanomaterials that have the potential to become aerosolized and inhaled during typical workplace tasks. (Other exposure routes such as dermal contact are not considered.) The document outlines a comprehensive program of occupational hygiene for dealing with nanomaterials for which occupational exposure levels have not yet been established.

Outline:

- General Guidance
- Materials within Scope: Unbound Engineered Nanoparticles
- Principal Elements of a Program to Minimize Exposure
- Hazard Assessment and Evaluation
- Exposure Assessment and Exposure Risk Evaluation
- Exposure Minimization Methods
- Exposure Minimization and Handling in Particular Occupational Settings
- Responding to Accidental or Unanticipated Releases of UNP
- Personal Protective Equipment
- Communication of Potential Hazards

ISO created a **T**echnical **C**ommittee 229 to create standards for nanotechnologies.

This committee produced a **T**echnical **R**eport ISO/TR 12885 on health and safety practices in 2008.

TR 12885 is more a compilation of known information about safe handling of nanomaterials rather than a hands-on guide. This document relies heavily on NIOSH's "Approaches to Safe Nanotechnology: An Information Exchange with NIOSH"

Additional Details:

- The ASTM standard guide is available for purchase at http://www.ASTM.org by searching for E2535
- The ISO standard is available for purchase at http://www.iso.org by searching for 12885

Module 7: Tools and Resources for Further Study

Lesson Overview

The purpose of this module is to provide you with resources to enhance your self-education in the future.

These topics will be covered:

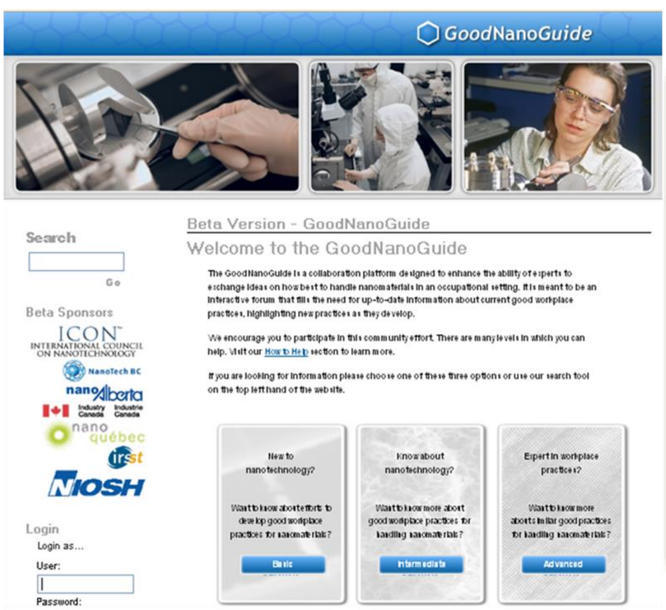
- Overview of sites and tools presented so far
- The GoodNanoGuide
- Other helpful websites

Learning Objectives

At the end of this module you will be able to

- Articulate several tools that are available for keeping your knowledge up-to-date
- Understand where to find and how to use these tools

Topic 1: The GoodNanoGuide



http://GoodNanoGuide.org

Protected Internet resource on occupational practices for the safe handling of nanomaterials

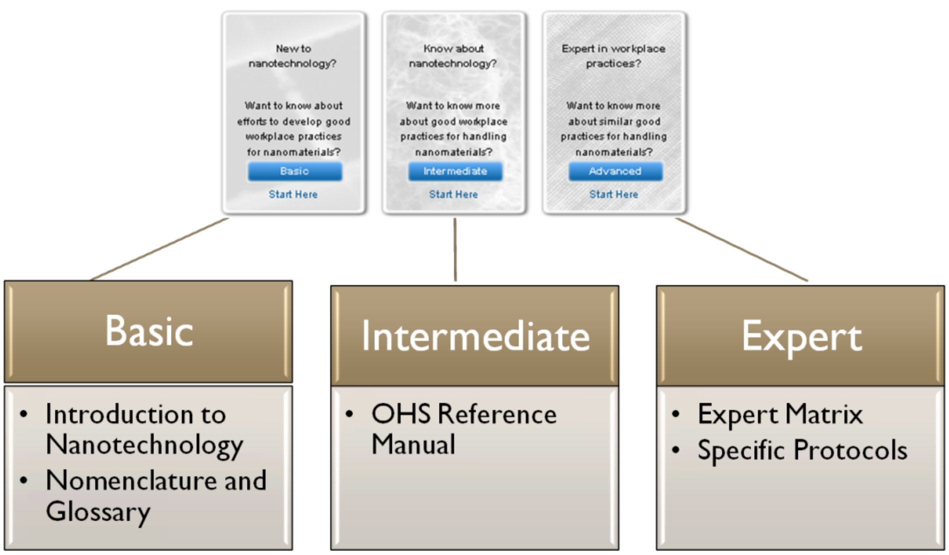
- LEARN best practices
- USE interactive information sharing system
- SEE new practices as they are developed
- CONNECT to other key information sources

Community driven; Collaborative

Why a Wiki for Nano Handling Practices?

Features	Guidance Document	Research Paper	Wiki Entry
Describes a specific practice	No	Maybe	YES
Written by practitioners	Maybe	Maybe	YES
Written for practitioners	Maybe	No	YES
Engages global community	No	Maybe	YES
Provides a forum for dialog	No	No	YES
Easily accessed	YES	No	YES

How Content is Organized



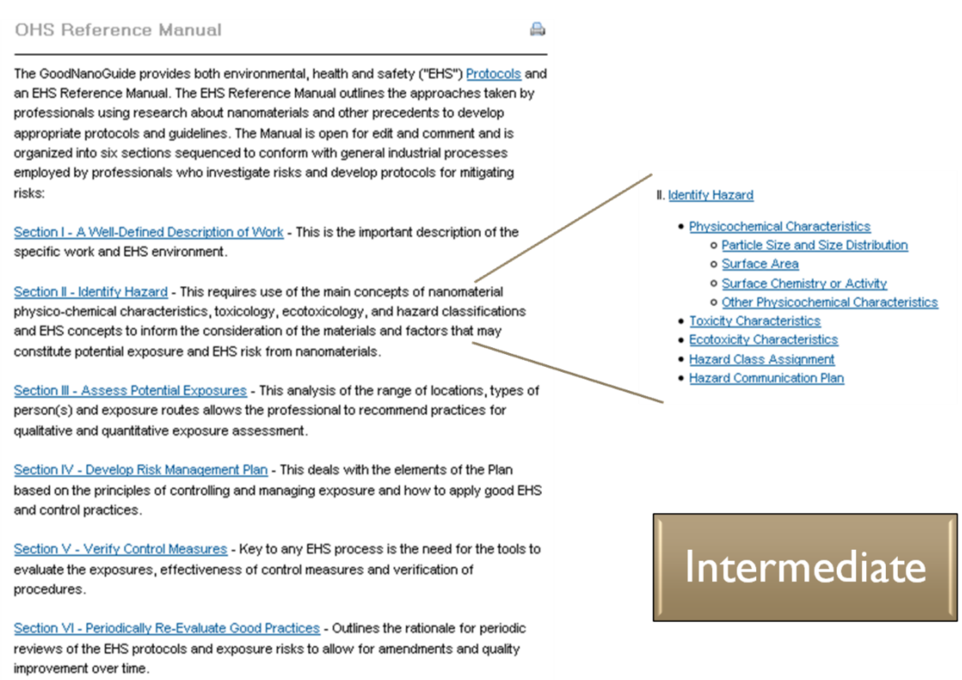
Interacting with the GoodNanoGuide

VIEW — No Registration Required

COMMENT — Register as a Community Member

CONTRIBUTE — Register as an Expert Provider

OHS Reference Manual



OHS Reference Manual

The GoodNanoGuide provides both environmental, health and safety ("EHS") Protocols and an EHS Reference Manual. The EHS Reference Manual outlines the approaches taken by professionals using research about nanomaterials and other precedents to develop appropriate protocols and guidelines. The Manual is open for edit and comment and is organized into six sections sequenced to conform with general industrial processes employed by professionals who investigate risks and develop protocols for mitigating risks:

Section I - A Well-Defined Description of Work - This is the important description of the specific work and EHS environment.

Section II - Identify Hazard - This requires use of the main concepts of nanomaterial physico-chemical characteristics, toxicology, ecotoxicology, and hazard classifications and EHS concepts to inform the consideration of the materials and factors that may constitute potential exposure and EHS risk from nanomaterials.

Section III - Assess Potential Exposures - This analysis of the range of locations, types of person(s) and exposure routes allows the professional to recommend practices for qualitative and quantitative exposure assessment.

Section IV - Develop Risk Management Plan - This deals with the elements of the Plan based on the principles of controlling and managing exposure and how to apply good EHS and control practices.

Section V - Verify Control Measures - Key to any EHS process is the need for the tools to evaluate the exposures, effectiveness of control measures and verification of procedures.

Section VI - Periodically Re-Evaluate Good Practices - Outlines the rationale for periodic reviews of the EHS protocols and exposure risks to allow for amendments and quality improvement over time.

II. Identify Hazard

- Physicochemical Characteristics
  - Particle Size and Size Distribution
  - Surface Area
  - Surface Chemistry or Activity
  - Other Physicochemical Characteristics
- Toxicity Characteristics
- Ecotoxicity Characteristics
- Hazard Class Assignment
- Hazard Communication Plan

Intermediate

OHS Expert Matrix

Assessment should
- Look at the form of the nanoparticle
- Consider the entire process

Expert

Nanoparticles in: →	Dry Powder	Liquid Dispersion	Solid Polymer Matrix	Nonpolymer Matrix
First Step: Identify	Potential Hazard	Potential Hazard	Potential Hazard	Potential Hazard
Second and Third Steps: Risk Assessment and Management				
Material Unpacking	Exposure Potential	Exposure Potential	Exposure Potential	Exposure Potential
	Controls	Controls	Controls	Controls
Synthesis	Exposure Potential	Exposure Potential		
	Controls	Controls		
Weighing and Measuring	Exposure Potential	Exposure Potential	Exposure Potential	Exposure Potential
	Controls	Controls	Controls	Controls
Dispersing	Exposure Potential	Exposure Potential		
	Controls	Controls		
Mixing	Exposure Potential	Exposure Potential		
	Controls	Controls		
Spraying	Exposure Potential	Exposure Potential	Exposure Potential	Exposure Potential
	Controls	Controls	Controls	Controls
Machining	Exposure Potential	Exposure Potential	Exposure Potential	Exposure Potential
	Controls	Controls	Controls	Controls
Packing	Exposure Potential	Exposure Potential	Exposure Potential?	Exposure Potential?
	Controls	Controls	Controls	Controls
Process Equipment Cleaning	Exposure Potential?	Exposure Potential?	Exposure Potential?	Exposure Potential?
	Controls	Controls	Controls	Controls
Workspace Cleaning	Exposure Potential	Exposure Potential	Exposure Potential	Exposure Potential
	Controls	Controls	Controls	Controls
Spill Cleanup	Exposure Potential	Exposure Potential	Exposure Potential	Exposure Potential
	Controls	Controls	Controls	Controls
Waste Management	Exposure Potential?	Exposure Potential?	Exposure Potential?	Exposure Potential?
	Controls	Controls	Controls	Controls
	Environmental Procedures	Environmental Procedures	Environmental Procedures	Environmental Procedures
Reasonably Foreseeable Emergencies	Exposure Potential	Exposure Potential	Exposure Potential	Exposure Potential
	Controls	Controls	Controls	Controls
	Environmental Procedures	Environmental Procedures	Environmental Procedures	Environmental Procedures

Please click here to access the OHS Reference Manual

Some Usage Metrics

- 700 visits per day; 18,600 page views; 3.62 average page views
- 4000 unique visitors
- 100 countries

Topic 2: Sites and Tools Presented so Far

OSHA Nanotechnology Topic Page:
http://www.osha.gov/dsg/nanotechnology/nanotechnology.html

What you'll find here

- Relevant OSHA standards
- Links to resources on Health Effects and Workplace Assessments and Controls

NIOSH Nanotechnology Topic Page:
http://www.cdc.gov/niosh/topics/nanotech/default.html

What you'll find here

- Recommendations and Guidance
- News on OHS

International Council on Nanotechnology:
http://icon.rice.edu

What you'll find here

- News on NanoEHS developments
- Virtual Journal of NanoEHS
- Industry Survey

The NanoRisk Framework:
http://nanoriskframework.org/

What you'll find here

- The EDF-DuPont framework document
- Case Studies

Control Banding Nanotool:
http://controlbanding.net

What you'll find here

- CB Nanotool
- Instruction Sheet
- Nanomaterial Field Form

Project on Emerging Nanotechnologies:
http://nanotechproject.org/

What you'll find here

- Policy Reports
- Consumer Product Inventory

NIEHS Worker Training Document:
http://is.gd/NIEHSnano

What you'll find here

- Introductory information on nanotechnology

- Guidance for trainers

EPA Regulations Relevant to Nanotech:
http://www.epa.gov/oppt/nano/;
http://www.epa.gov/pesticides/about/intheworks/nanotechnology.htm

What you'll find here

- Nano and the Toxic Substances act
- Nano and the Pesticides act

Standards:
http://www.astm.org/Standards/E2535.htm;
http://www.iso.org/iso/catalogue_detail?csnumber=52093

What you'll find here

- ASTM E2535-2007 Standard Guide for Handling Unbound Engineered Nanoscale Particles in Occupational Settings
- ISO/TR 12885:2008 Nanotechnologies—Health and safety practices in occupational settings relevant to nanotechnologies

Topic 3: Other Useful Information

The US National Nanotechnology Initiative
http://nano.gov

What you'll find here

- Nanotech Facts
- Occupational Safety Links
- Materials for Educators

California Department of Toxic Substances Control
http://www.dtsc.ca.gov/technologydevelopment/nanotechnology/index.cfm

What you'll find here

- Nanotechnology Reports
- Comprehensive information on the data call-ins, including company submissions for carbon nanotubes

European Commission Enterprise and Industry: REACH and Nanomaterials
http://ec.europa.eu/enterprise/sectors/chemicals/reach/nanomaterials/index_en.htm

What you'll find here

- Background information on European toxic substances legislation known as REACH
- Paper: Nanomaterials in REACH
- Paper: Classification, Labelling and Packaging of Nanomaterials in REACH and CLP

Do you know any others?