Engineering Controls for Nanotechnology

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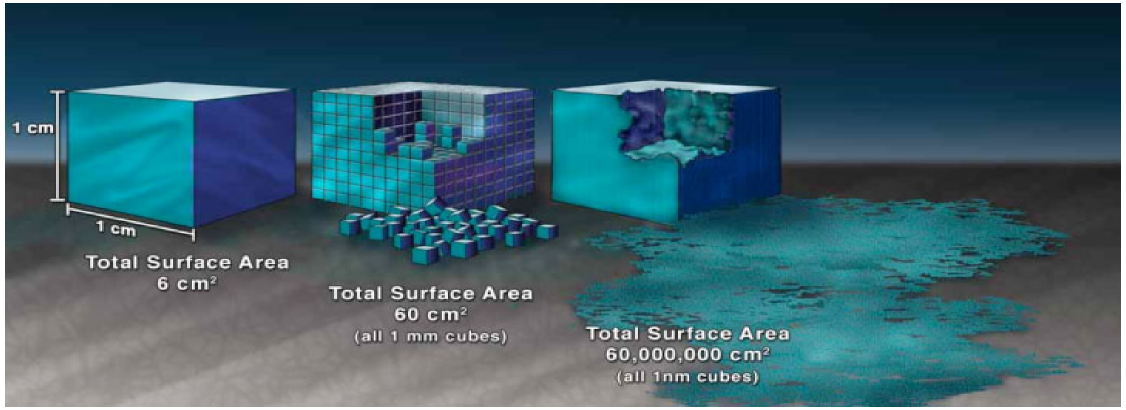
The findings and conclusions in this presentation are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

Nanomaterials

- 1 -100 nanometer size
- Special properties
- Naturally occurring (incidental) and specifically engineered

Small size → **Large surface area**



Source: Nano.gov

Nanotoxicology- key findings

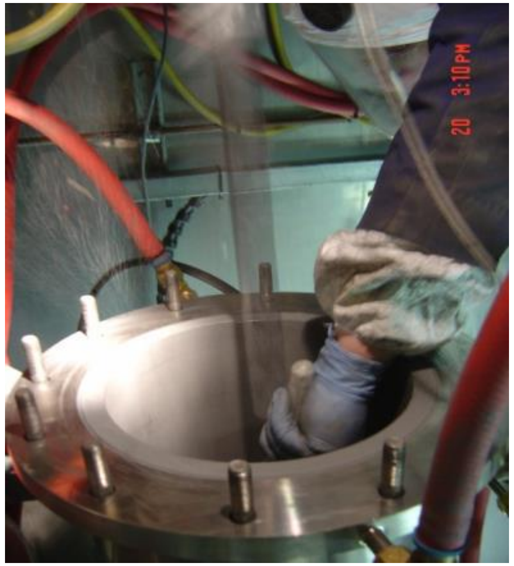
- Pulmonary exposure to:
  - Single-walled carbon nanotubes (SWCNT) causes rapid and persistent fibrosis in mice
  - Multi-walled carbon nanotubes (MWCNT) can reach the intrapleural space in mice (site of mesothelioma for asbestos)
  - SWCNT can interfere with cell division (in petri dish)
- Certain nanoparticles (SWCNT or titanium dioxide) can cause cardiovascular dysfunction in mice
- MWCNT or titanium dioxide nanowires can induce inflammatory mediators in certain regions of the brain in mice
- IARC classified one type of CNT (MWCNT-7) as 'possibly carcinogenic to humans (Group 2B)'

NTRC Research Program: 10 Critical Topic Areas

1. Toxicology and internal dose
2. Measurement methods
3. Exposure assessment
4. Epidemiology and surveillance
5. Risk assessment
6. **Engineering controls** and PPE
7. Fire and explosion safety
8. Recommendations and guidance
9. Global collaborations
10. Applications

A concurrent approach to match the pace of innovation.

Potential Exposure Examples from NIOSH Field Teams

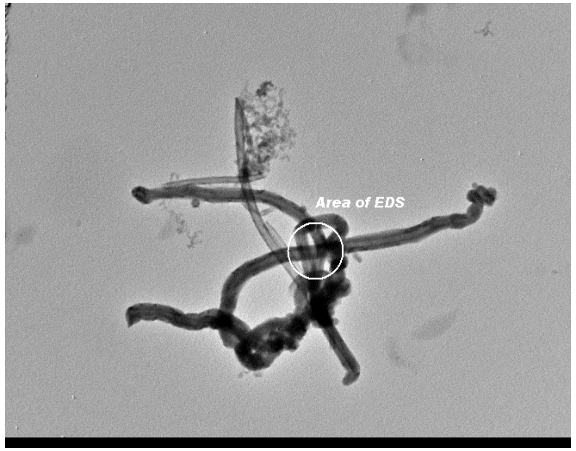





Workplace photos courtesy of M. Methner, NIOSH.

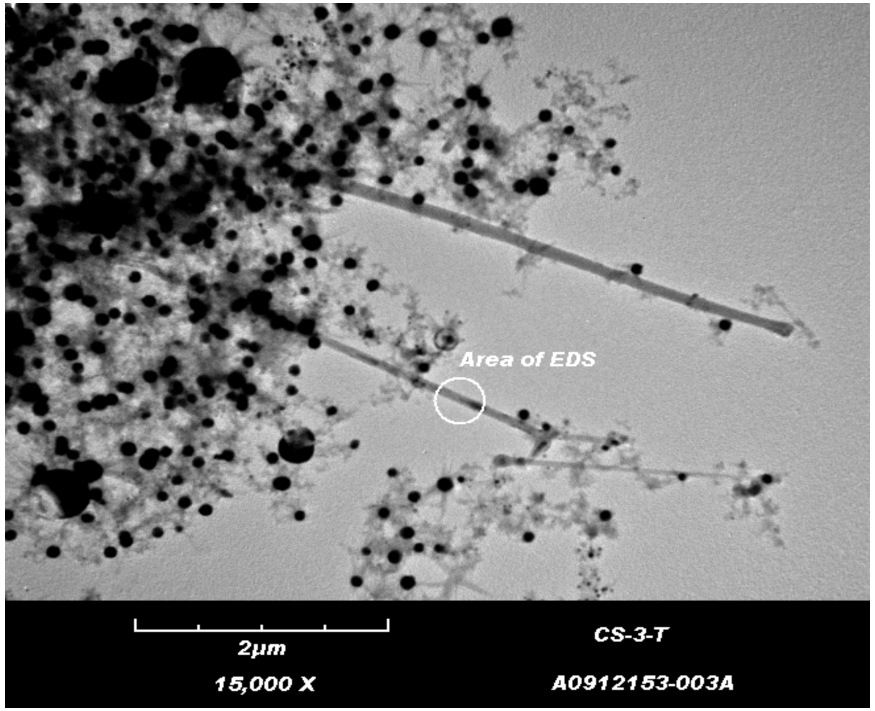
Weighing CNF's inside laboratory fume hood

PBZ indicates CNF's reach breathing zone and could escape and contaminate adjacent areas/entire lab



Harvesting SWCNTs from a Carbon Arc Reactor

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



Field Assessment of Engineering Controls

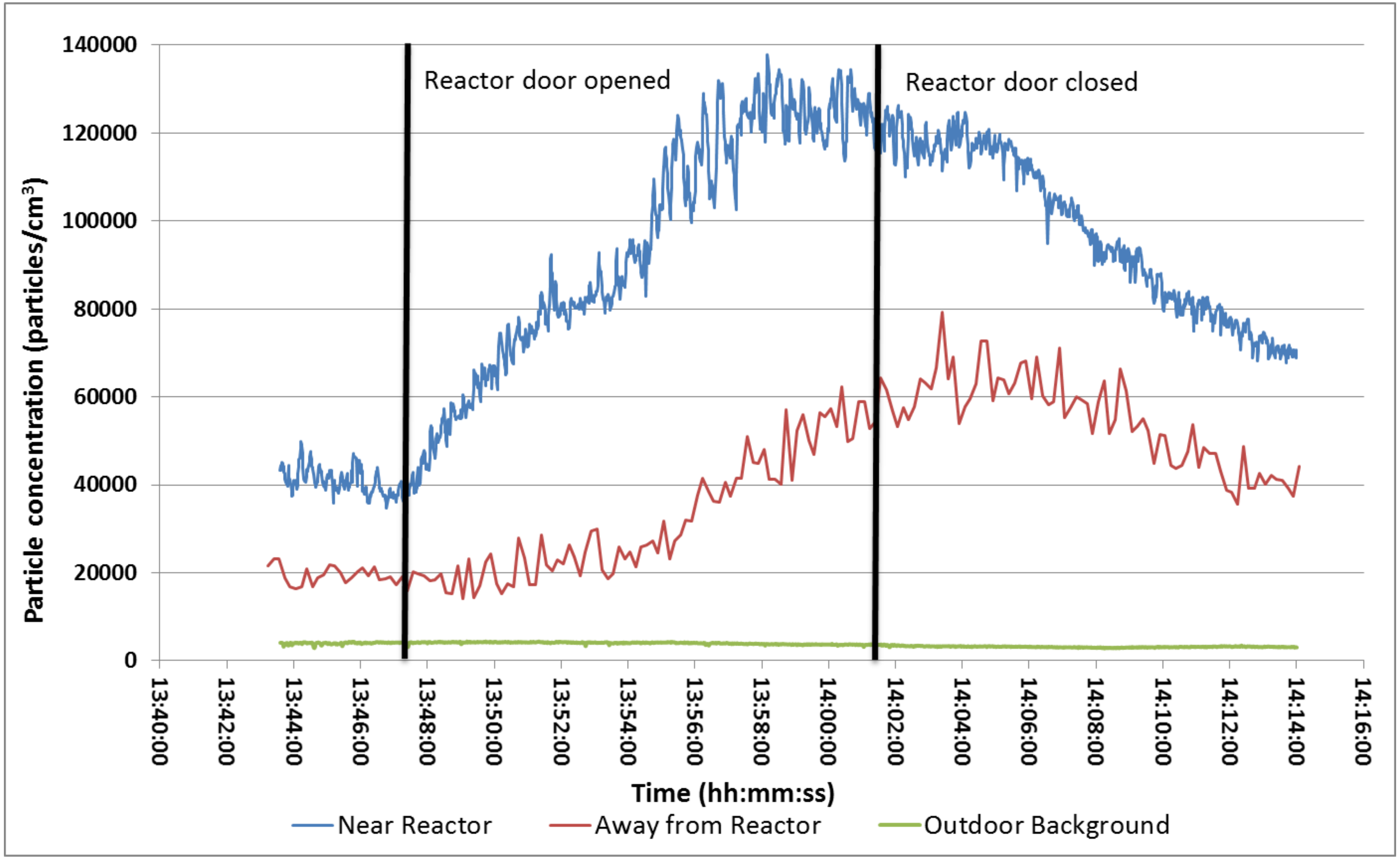
- **Conducted engineering control evaluations in several facilities, including:**
  - Carbon nanotube (CNT) and graphene producers
  - CNT composite manufacturers
  - Nano metal oxide producers
  - Nanocellulose producers
  - Academic laboratories
- **These evaluations typically include:**
  - identification of emission sources;
  - background and area monitoring;
  - air concentration measurement by direct-reading instruments and filter-based sampling;
  - measurement of air velocities and patterns, and;
  - evaluation of engineering control effectiveness

Current Knowledge

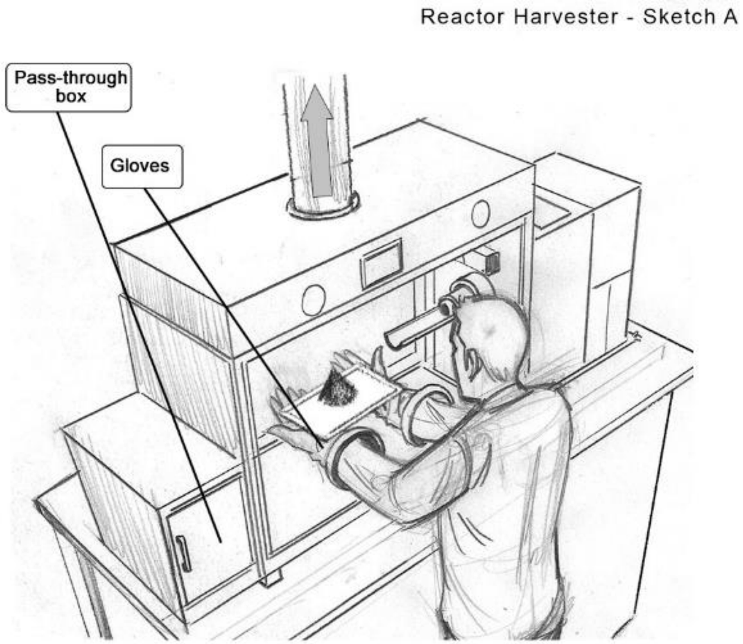
- **Exposure studies have been conducted in a variety of nanotechnology facilities**
- **We know where the potential for exposure exists:**
  - Leakage from reactors and powder processing equipment
  - Manually harvesting product from reactors
  - Dumping/mixing of powders
  - Replacing "big bags" (bulk containers) of nanomaterial-containing powders
  - Spraying of liquids containing nanomaterials
  - Weighing out powder/packaging material
  - Changing filters on dust collection systems and vacuum cleaners

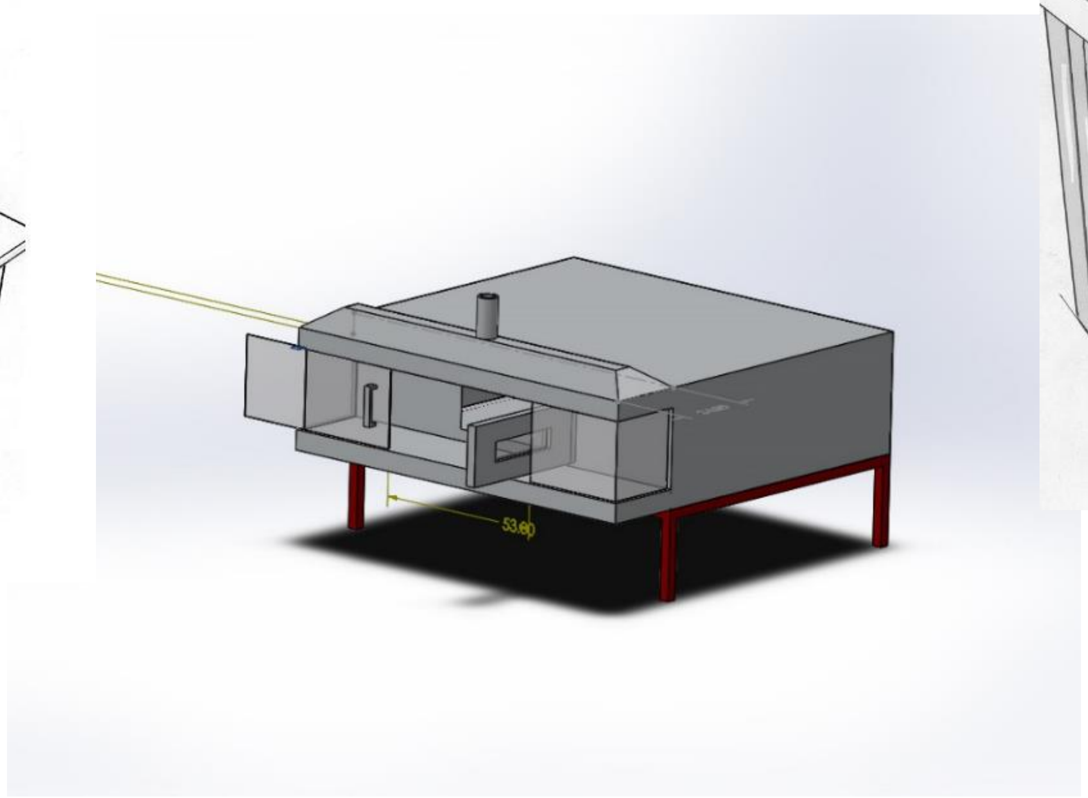
(Brouwer, D., Toxicology. 2010;269:120–127, Bekker at al., Ann. Occup. Hyg., 2015, 1–24)

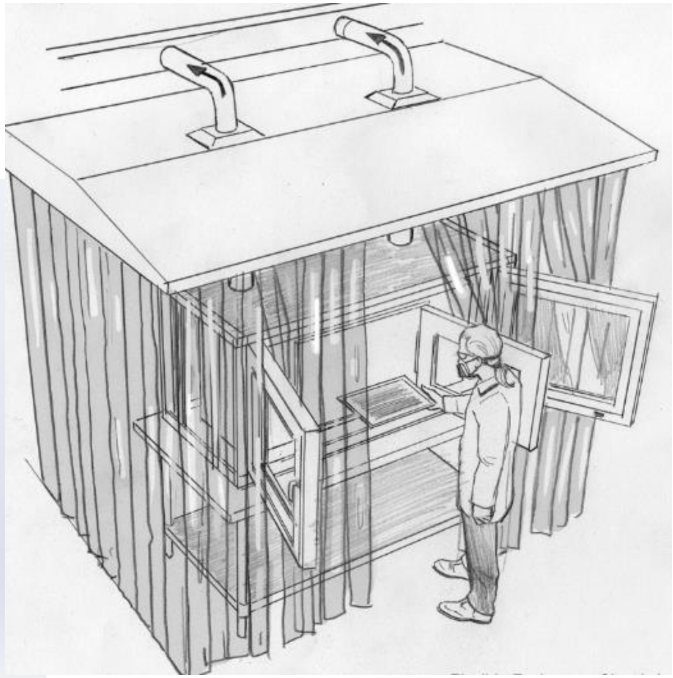
Reactor Harvesting



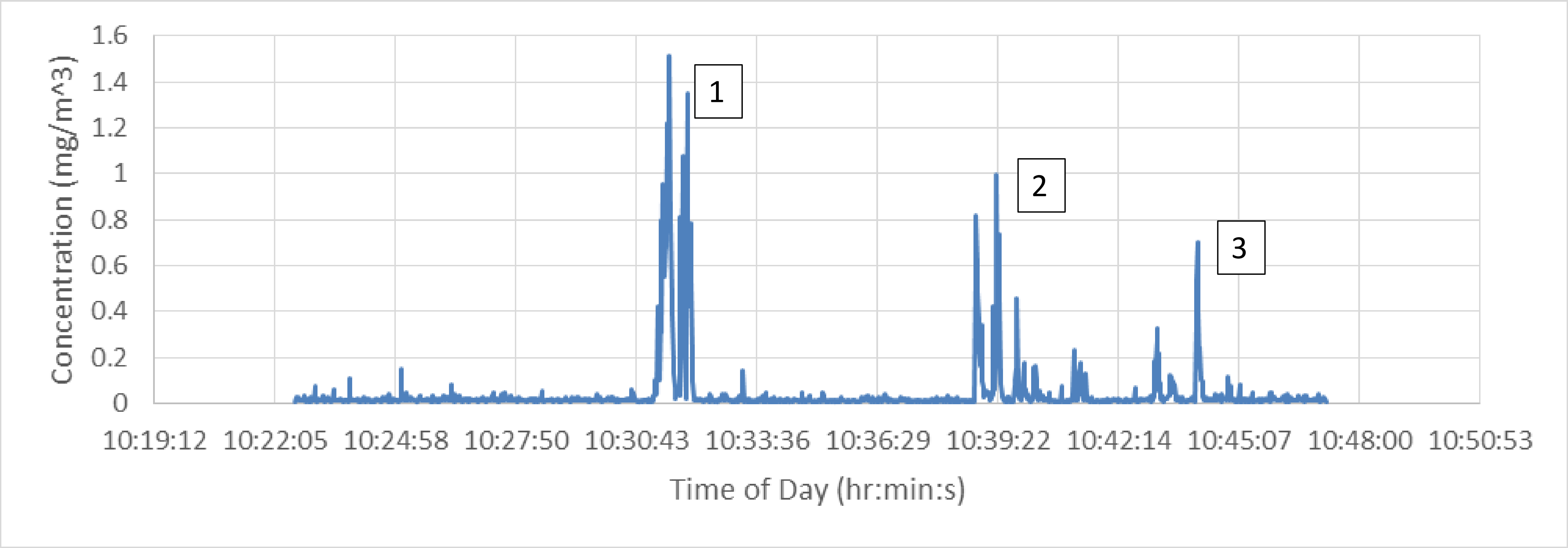
Enclosures for Reactor Harvesting





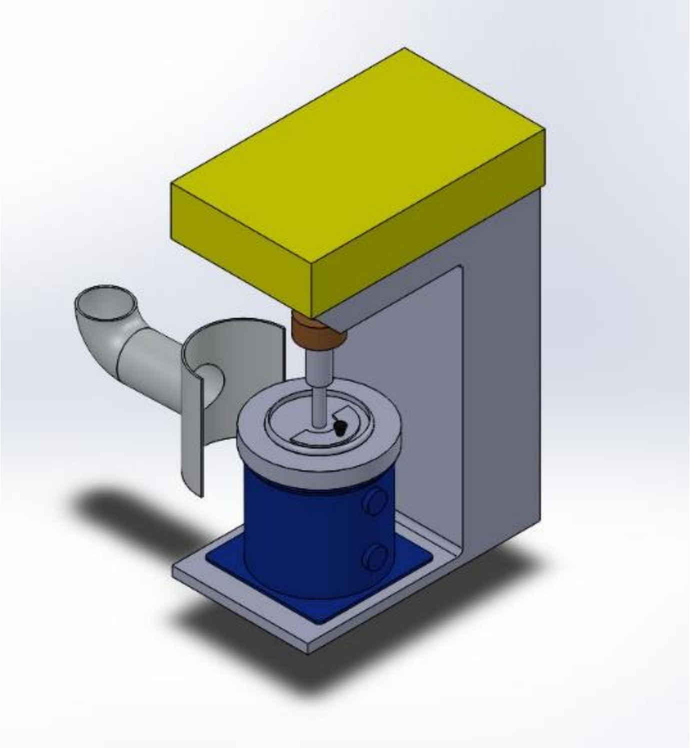


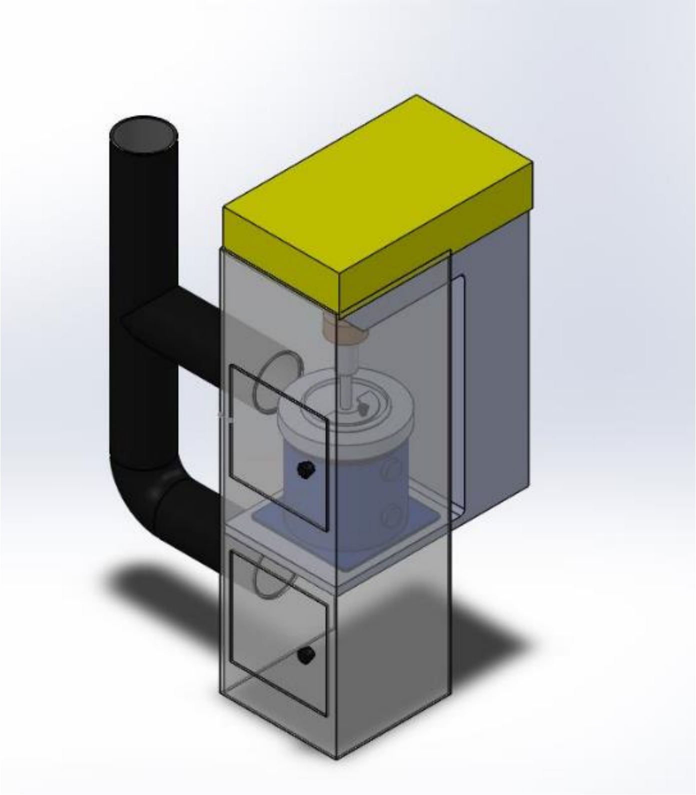
Ball Milling Emissions



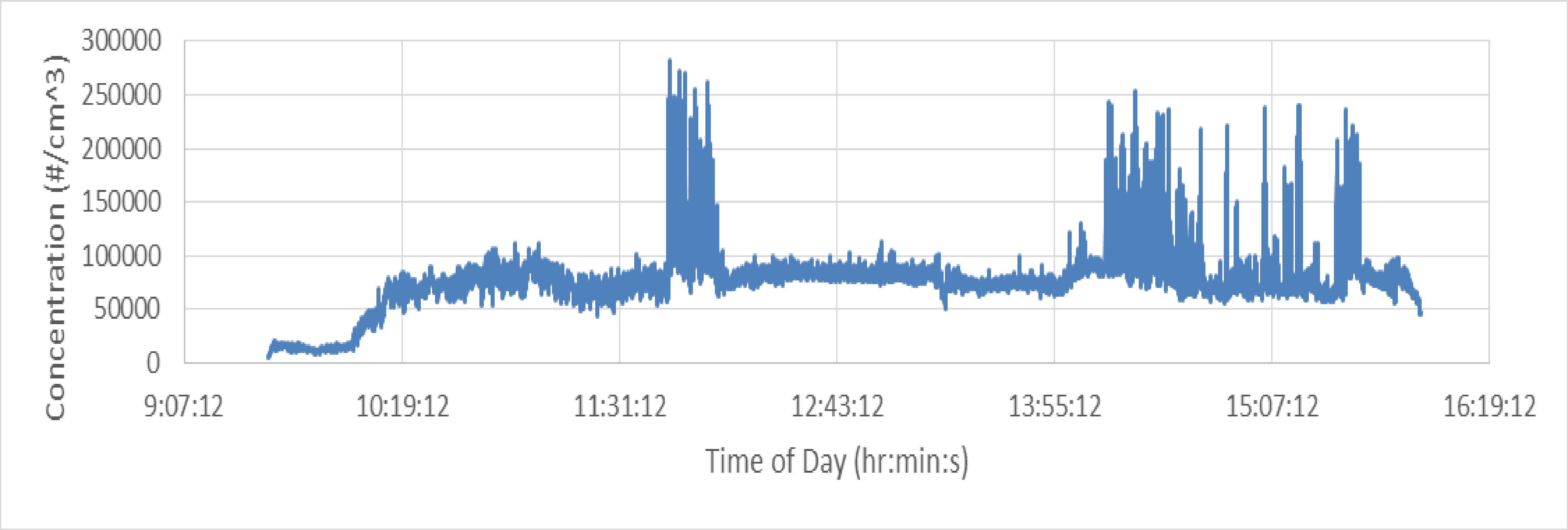
1. 10:30 – Valve at bottom of ball mill was opened to discharge product
2. 10:39 – Pouring and loading of mill is completed and lid is put back on mill.
3. 10:43 – Operator pours product back into ball mill

Ball Milling LEV Control Options



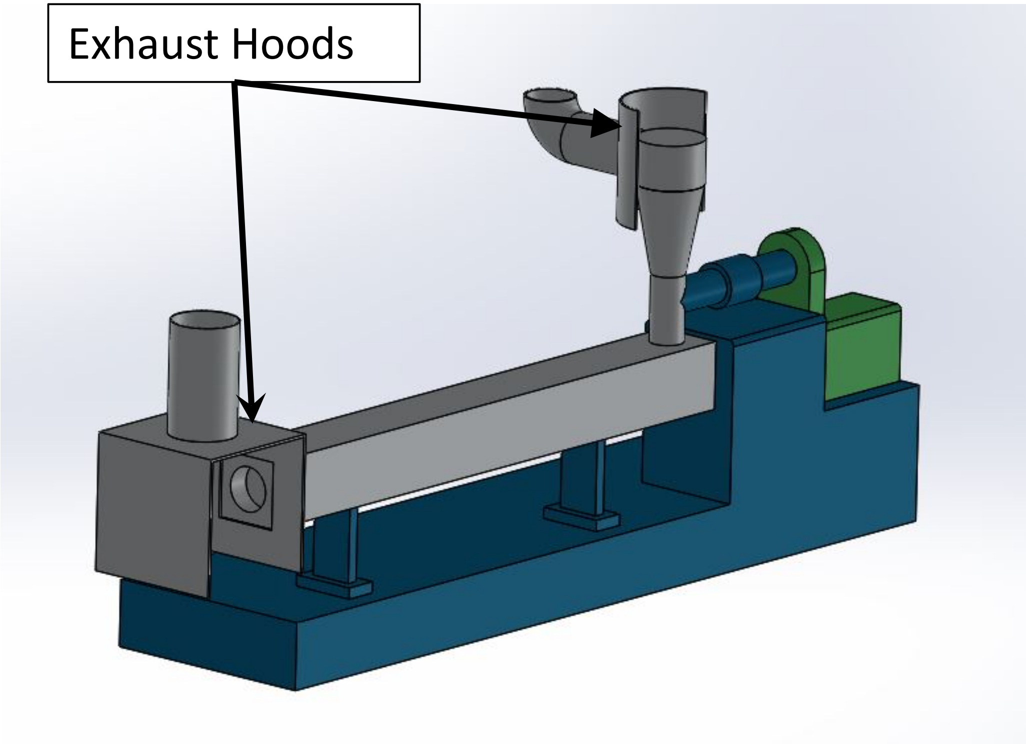


Control of Extruder Emissions

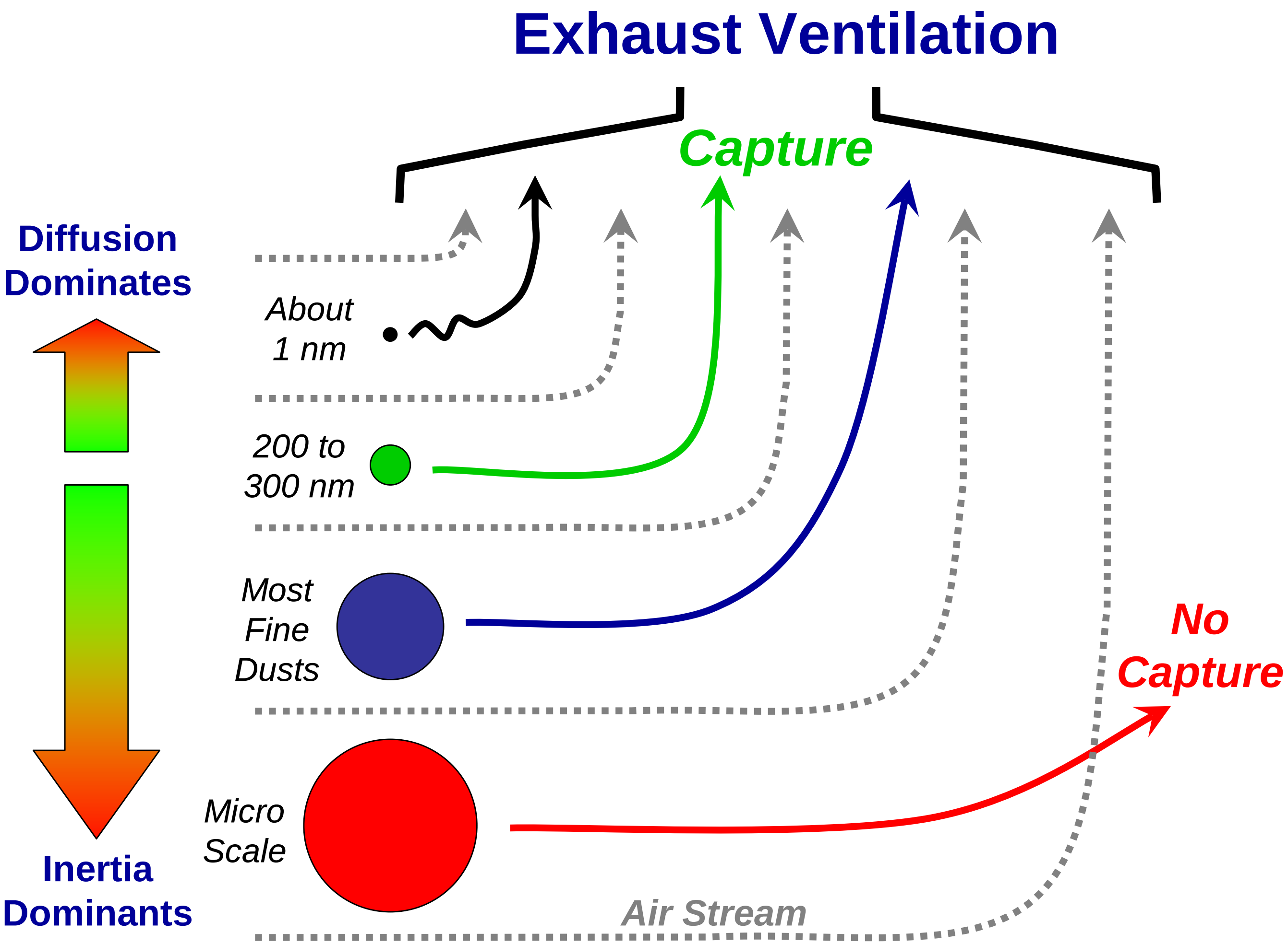


LEV for Screw Extruder

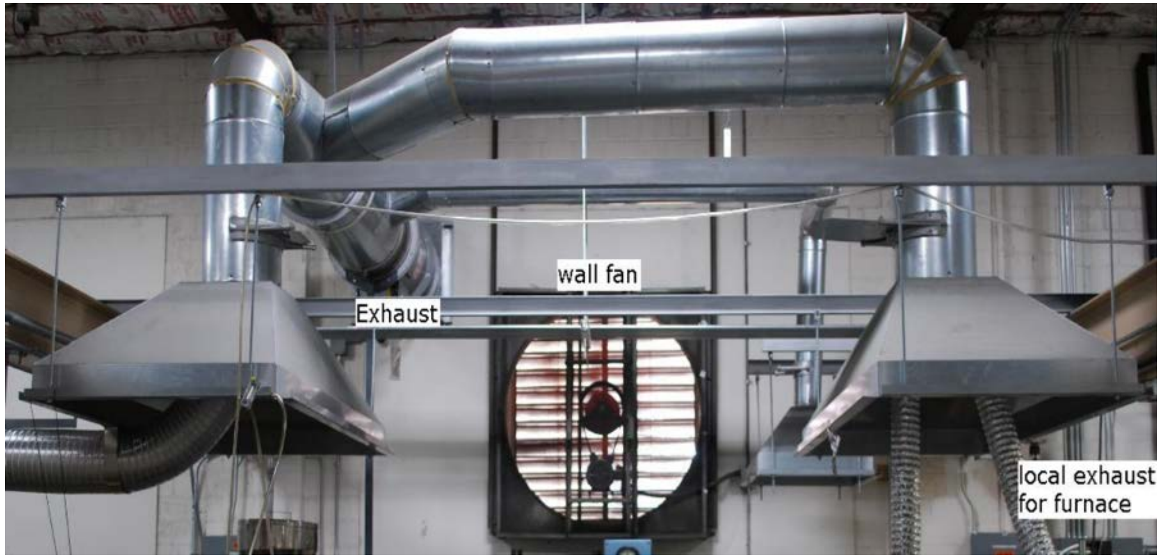
Source: http://www.globalextruder.com/pic/big/28_0.jpg



Conventional Controls Should Work

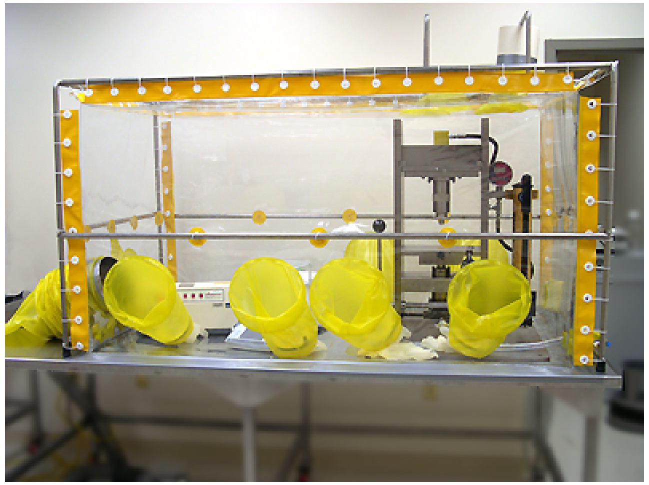


Engineering Control Examples from NIOSH Field Teams

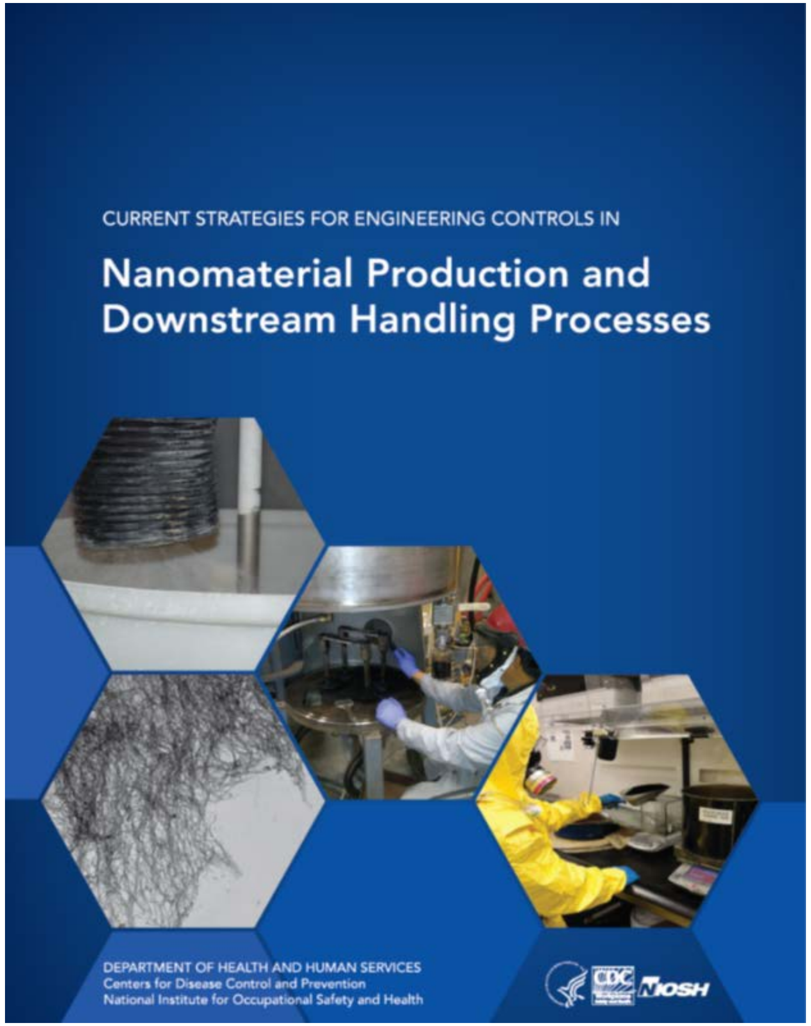


Engineering Controls for Common Processes

- Effective controls that factor budget and space limitations are available
- Select controls based on task-based exposure risks



Nano Controls Guidance



- In 2013, released "Current Strategies for Engineering Controls in Nanomaterial Handling and Downstream Processes"
  - Provides guidance regarding approaches and strategies to protect workers by using available engineering controls for engineered nanomaterials in the workplace.
  - Covers common processes including material weighing and handling, reactor harvesting and cleaning, bag dumping and large-scale material handling/transfer

http://www.cdc.gov/niosh/docs/2014-102/

Overview/Key Points

- **Identifies common production and downstream tasks associated with worker exposure, including:**
  - Leakage from reactors and powder processing equipment
  - Manually harvesting product from reactors
  - Transporting/transferring of intermediate products to the next process
  - Dumping powders into processing equipment
  - Weighing out powder/packaging material for shipment
  - Changing filters on dust collection systems and vacuum cleaners
  - Machining of products containing nanomaterials (e.g., cutting, grinding, drilling)

- **Provides potential for control approaches for each of these tasks and presents relevant research on control effectiveness**

- **Discusses approaches for evaluating control effectiveness**
  - The assessment of control effectiveness is essential for verifying that the exposure goals of the facility have been successfully met

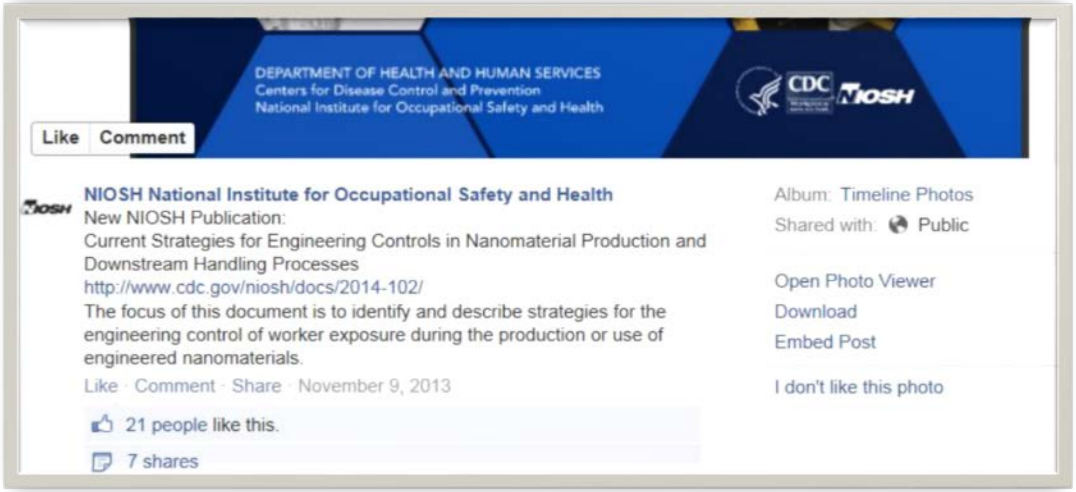
- **Provides list of sources of information on risk management and engineering control design guidance**

Table 2. Process/tasks and emission

Process/task	Potential emission/ exposure points	See section	See figures
Production of bulk nanomaterials	Reactor fugitive emissions	3.4.1	7, 8
	Product harvesting	3.4.1	12
	Reactor cleaning	3.4.1	
Downstream processing	Product discharge/bag filling	3.4.3.1	14, 15, 16
	Bag/container emptying	3.4.3.2	17
	Small-scale weighing	3.4.2	10, 11, 12, 13
	Machining of products	3.4.3.4	
Product packaging	Small-scale weighing/handling	3.4.2	10, 11, 12, 13
	Large-scale weighing/handling	3.4.3.3	18
	Product packaging	3.4.3	14, 15, 16, 18
Maintenance	Facility equipment cleaning	3.4.4	
	Air filter change-out	3.4.4.1	19
	Spill clean-up	3.4.4.2	

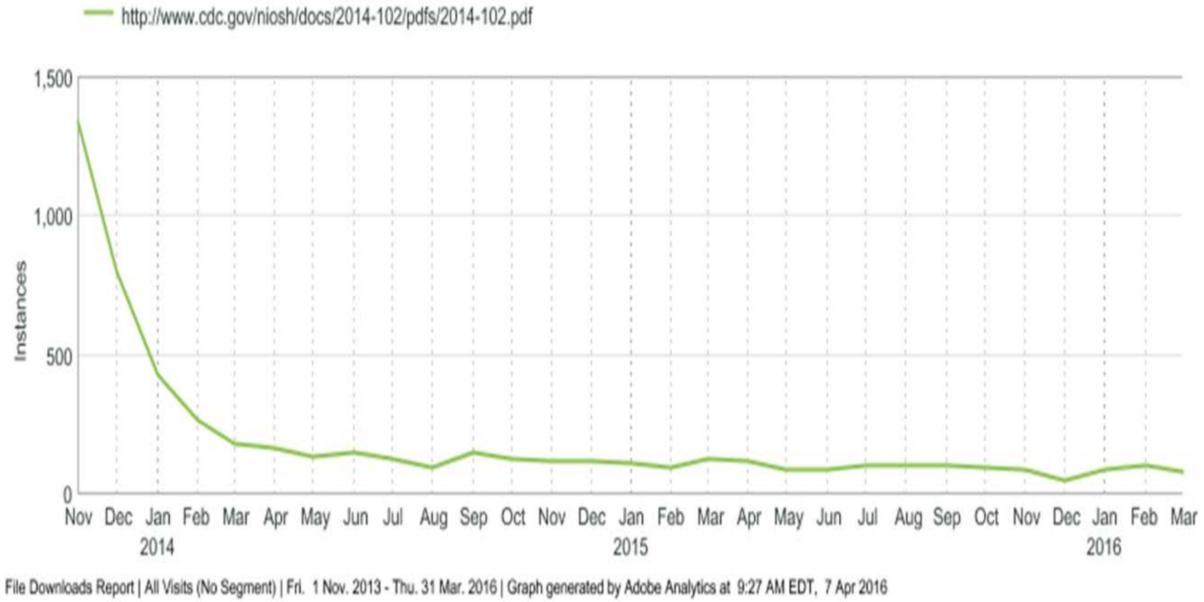
Dissemination Activities

- Document Released on 11/22/2013
- Posted on NIOSH Web page
- Press Release
- Twitter activity
- NIOSH Facebook
- NIOSH eNews
- NIOSH Blog
- Wikipedia



Web Metrics

Web Traffic (as of 8/2016)	Instances
Page visits	7,395
Document Downloads	5,806 (79%)
Blog views	1,198



Should we continue to promote the Nano controls document?

Referring Domain	Instances	Percent
Typed / Bookmarked	1,871	40.4%
google.com	470	10.1%
OHS Online	349	7.5%
Nanowerk.com	172	3.7%
govdelivery.com	109	2.4%
EHStoday.com	100	2.2%

Next Steps--Short Engineering Info Sheets

Workplace design solutions

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

PtD Prevention through Design

Prevention through Design (PtD)

Prevention through Design (PtD) can be defined as designing out or eliminating safety and health hazards associated with processes, structures, equipment, tools, or work organization. The National Institute for Occupational Safety and Health (NIOSH) launched a PtD initiative in 2007. The mission is to reduce or prevent occupational injuries, illnesses, and fatalities by considering hazard prevention in the design, re-design, and retrofit of new and existing workplaces, tools, equipment, and work processes [NIOSH 2008a,b].

Protecting Workers during the Handling of Nanomaterials

Summary

Engineered nanomaterials are materials that are intentionally produced and have at least one primary dimension less than 100 nanometers (nm). Nanomaterials may have properties different from those of larger particles of the same material, making them unique and desirable for specific product applications. The health effects associated with nanomaterials are not yet clearly understood so it is important for producers and users of ENMs to reduce employee exposure and manage risks appropriately. In 2013, a compendium of control approaches for nanomaterial production and use processes entitled, Current Strategies for Engineering Controls in Nanomaterial Production and Downstream Handling Processes, was published by NIOSH [http://www.cdc.gov/niosh/docs/2014-102/pdfs/2014-102.pdf]. This Workplace Design Solutions is part of a series being developed from this document to provide concise guidance on exposure control approaches for the most common nano-manufacturing processes.

Background

The toxicity of many nanomaterials is presently unknown, but initial research indicates that there may be health concerns related to occupational exposures. Only a few types of engineered nanomaterials have undergone relatively extensive toxicological evaluation, e.g., titanium dioxide (TiO2) and carbon nanotubes (CNTs). Results from animal studies with TiO2 and other poorly-soluble, low-toxicity particles of fine and ultrafine (nanoscale) sizes have shown adverse pulmonary responses in exposed rats, including persistent pulmonary inflammation and lung tumors [NIOSH 2011; Oberdörster 2002; Donaldson 2009; Poland et al. 2012]. Similar toxicological responses have also been observed in rats and mice exposed to CNTs and carbon nanofibers (CNFs) [NIOSH 2013a]. Because of the potential for health effects, it is important to

Description of Exposure

Small-scale handling of nanopowders is a common task; examples include working with a quality assurance/control sample, weighing out a specific quantity for mixing/compounding and processing smaller quantities in downstream industries. The tasks of weighing out nanomaterials can lead to worker exposure primarily through the scooping, pouring, and dumping of these materials. Dahm et al. [2012] conducted exposure assessments at six manufacturers and users of carbon nanotubes and nanofibers. This study showed that the highest exposures occurred during dry powder handling tasks including mixing and weighing operations. Many different types of commercially available enclosures can be employed to reduce exposure during the handling of nanopowders. The controls described below include chemical fume hoods, nanomaterial handling enclosures, biological safety cabinets, and glove boxes. This sheet provides information on hood and laboratory design and operation, administrative controls (such as good work practices), and the use of personal protective equipment.

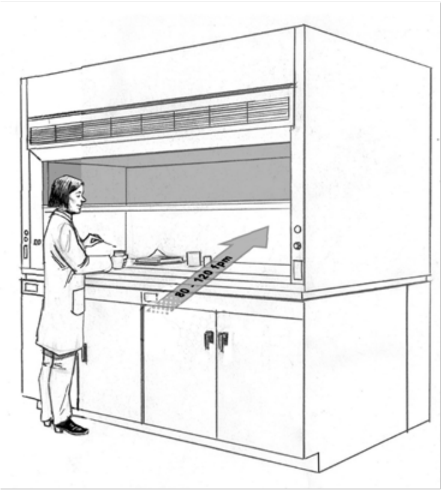
The National Institute for Occupational Safety and Health (NIOSH) recommends that manufacturers and downstream users of nanomaterials develop PtD strategies to protect workers during the handling of engineered nanomaterials. Engineering controls protect workers by removing hazardous conditions or placing a barrier between the worker and the hazard, and along with good material handling techniques, they are likely to be the most effective control strategy for nanomaterials. The identification and adoption of effective control technologies is an important first step in reducing the risk associated with worker exposure to

Engineering Controls

One engineering control used in the nanotechnology industry during the handling, weighing, mixing or sonication of engineered nanomaterials is a ventilated enclosure. These enclosures include fume hoods, nanomaterial handling enclosures, glove box isolators, and biological safety cabinets [NIOSH 2013b]. Each of these controls should be carefully designed and properly operated to be effective. Below is what you should know about each control and the limitations of their use.

Chemical fume hood

- Very common control used in many settings, including with nanomaterials.
- Effectively contains nanomaterials for a range of activities.
- Older versions with constant airflow were found to leak even at design face velocity [Tsai et al. 2009].
- Exhausts directly out of facility—not recirculated into workplace.
- Larger size, higher and potentially disruptive airflows compared to the nanomaterial handling enclosure.
- Higher energy costs for both fan motor and tempered replacement air than for low flow



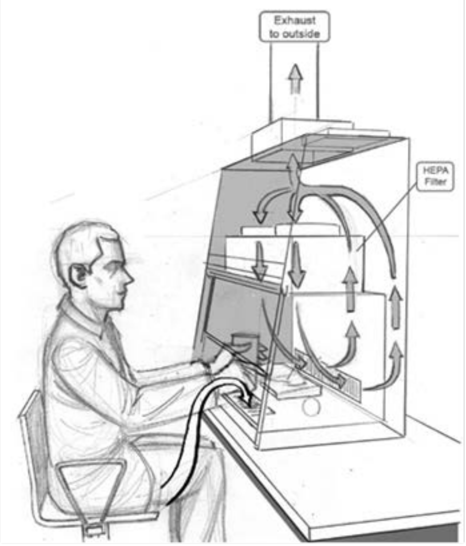
Short Engineering Info Sheets (cont.)

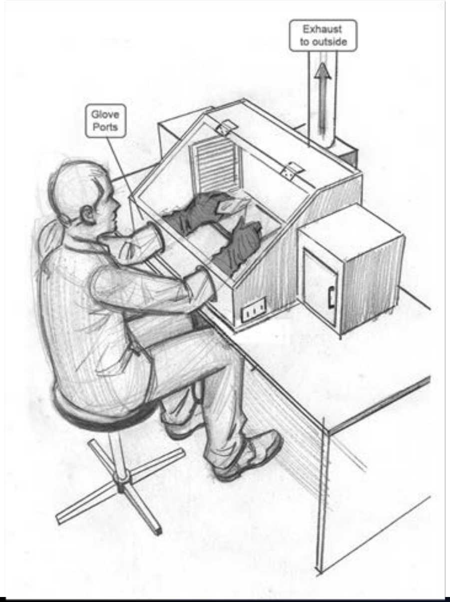
Nanomaterial Handling Enclosure

- Similar to pharmaceutical ventilated balance enclosures.
- Molded airfoils at edges, sill, and sash reduce turbulence.
- Some enclosures recirculate HEPA-filtered exhaust flows back into lab
- Recirculating hoods are not appropriate for work with hazardous chemicals, such as solvents, which are not removed by HEPA particulate filters.
- Generally smaller and lower flow than chemical fume hoods.
  - ⇒ Provide improved environment for weighing/handling nanomaterials.
  - ⇒ Protection may be compromised by airflow

Biological Safety Cabinet

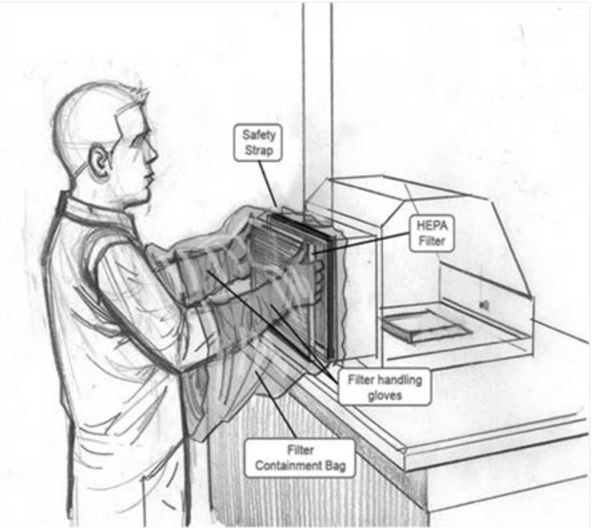
- Primary use is working with biological aerosols.
- There are several different types of BSCs, so care must be taken to understand the applicability of the hood for providing personnel protection when handling nanomaterials.
- The most common BSC, a Class II hood, protects both personnel and product by containing the work while providing clean air to work surface.
- BSCs may recirculate HEPA-filtered air to work room and/or exhaust directly to outside.
  - ⇒ Recirculating hoods are not appropriate for work with hazardous chemicals, such as solvents, which are not removed by HEPA particulate filters.
  - ⇒ Canopy connections (BSC Class II Type A2) are preferred for BSCs that exhaust to the outside.
- The downward air flow toward the work surface may make BSCs problematic when working with





Glovebox

- Highest level of protection for working with nanomaterials or other hazardous chemicals.
- Gloveboxes should be maintained at negative pressure so leaks are into the box rather than out of the box.
- These devices may be awkward to use due to restricted arm movements and difficulty seeing the process clearly.
- Units require periodic inspection to look for tears in gloves and leaks.
- Energy costs are generally lower than other controls discussed here since very little exhaust flow is required to maintain



Bag in-Bag Out Filter Change out

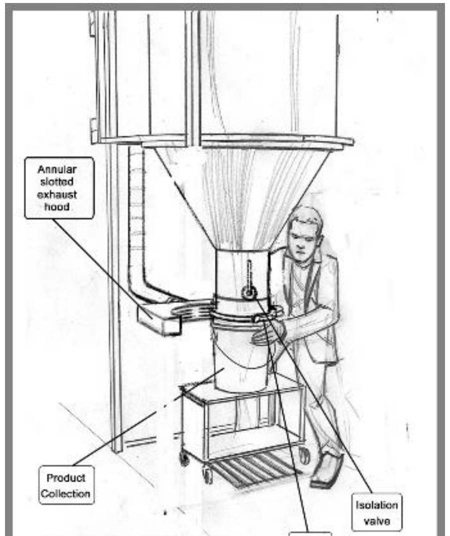
- Allows for removal of a dirty air filter while minimizing worker exposure.
- The containment bags often have integral gloves to make removing filter easier.
- A filter containment bag is attached to a service port on the unit by a safety strap.
- Bags with contaminated filters are cinched, closed, and disposed of properly .
- This process contains the filter with its contaminants so the worker is not exposed and the particulates are not resuspended in the workplace

Summary

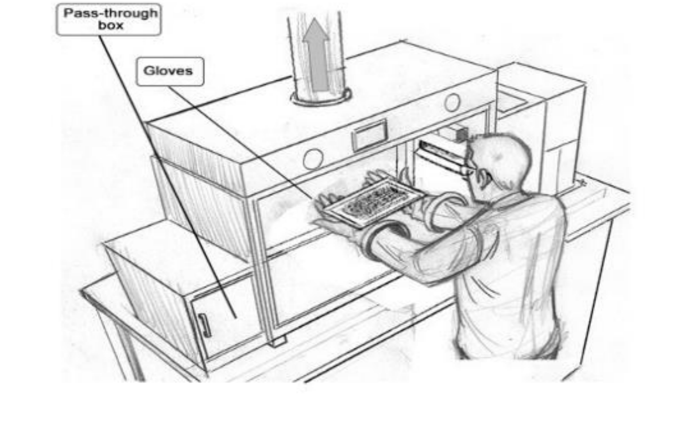
- We have a good understanding of how exposures occur and how to control them.
  - Need to continue to conduct field studies to identify new processes and materials
  - Should we be doing any laboratory work on quantifying control effectiveness?
- We need to have a better understanding of how to communicate with our target audience.
  - How do we effectively target our audience—small companies and engineering/IH consultants?
  - What are the best channels for dissemination?

Future Plans

- Plan to develop 3 additional Workplace Design Solutions (WDS) on common nanotech tasks/processes, including:
  - Reactor Operations (harvesting and cleaning)
  - Powder collection/dumping (large bag dumping and powder packing)
  - large scale material handling
- Is this type of a product useful to the small producers and users of nanomaterials?
- How do we evaluate the usefulness of the information with the target audience?
- How do we identify companies needing this information?



Sketch A - Spray Drier

Reactor Harvester - Sketch A



Sketch A - Bag Dump Station

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