National Institute for Occupational Safety and Health

Nanotechnology: The New Workplace

Safe Development of Nanotechnology

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Nanotechnology: The Scope

Anything you can imagine can be made faster, stronger, smarter, smaller, better, etc., using nanomaterial science. So, nanotechnology is coming to you, as a producer, user or consumer.

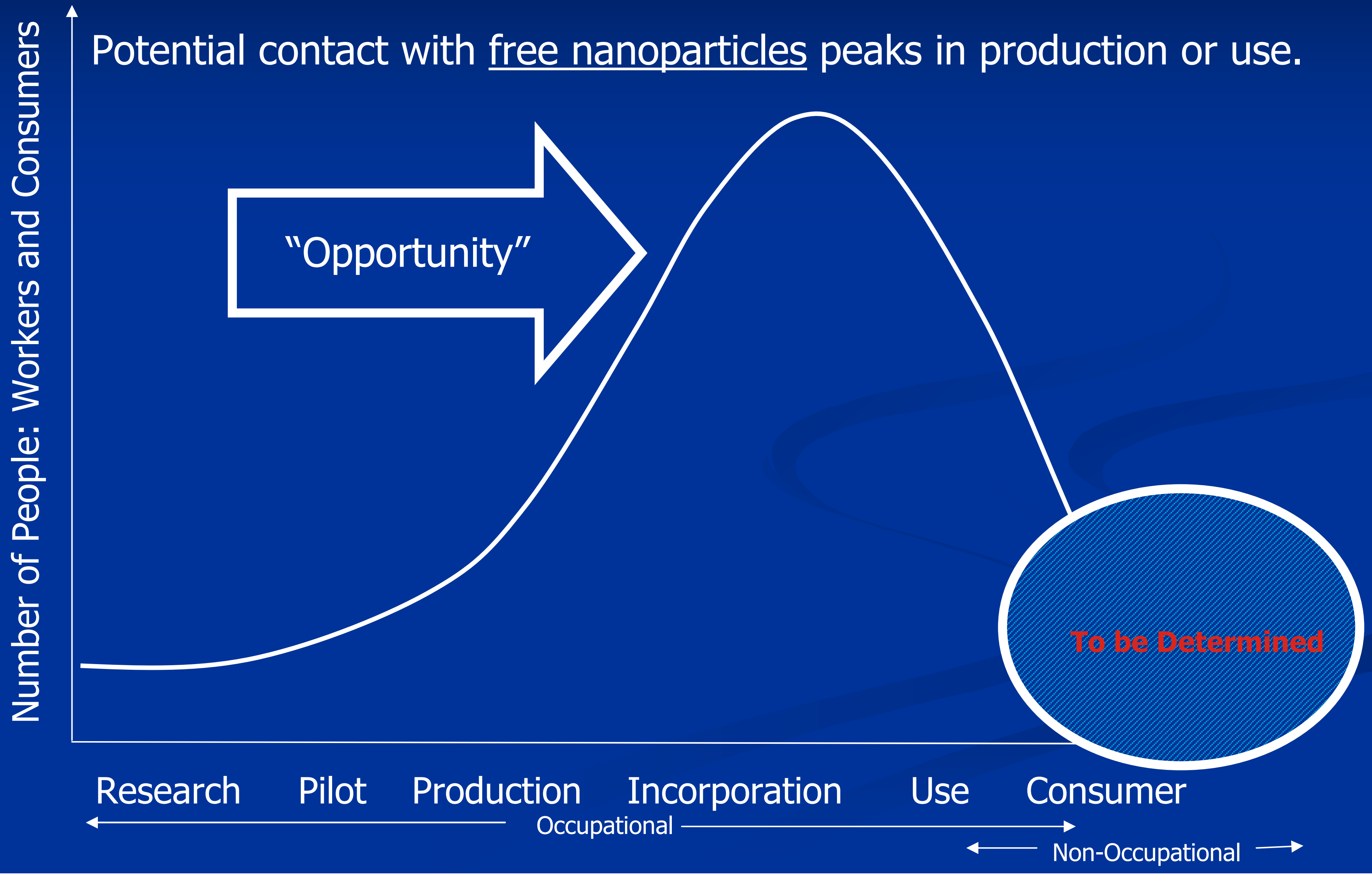
Will nanotechnology change everything as we know it?

Most certainly!

Where will nanotechnology have an impact?

- **Materials**
  - Nano-enabled composites
  - Reinvented material science
- **Energy/Electronics**
  - Power generation
  - Computing ability
- **Medical/Biological**
  - "Smart" drugs
  - Imaging
  - Disease detection and treatment
- **Food and Agriculture**
  - Production
  - Improved Nutritional Value
- **Pollution**
  - Prevention/treatment
  - Air quality
  - Water Quality

Characterize the Extent of Exposure to Free Nanomaterials: The Real OS&H Challenge



Challenge: The diversity of "Nanomaterial Production and Use"

Nanotechnology: Safe Assumptions

- Properties that may yield societal benefits may also lead to hazards and risks: unknowns exist
- Rapid evolution of the technology
- Prime focus is on the engineered nanoparticle
- R&D and pilot processes deal with the newest materials
- Earliest exposures will be in the workplace
- Hazard (Toxicology) picture is incomplete
- Exposure data are needed to understand risk
- A reasonable and prudent approach is needed

Logical Course of Action?

An Overall Risk Management Approach

Key Elements of Risk Management

Hazard Identification

"Is there reason to believe this could be harmful?"

↓

Exposure Assessment

"Will there be exposure in real-world conditions?"

↓

Risk Characterization

"Is substance hazardous *and* will there be exposure?"

↓

Risk Management

"Develop procedures to minimize exposures"

Adapted from Gibbs, 2006

What does the Industrial Hygienist bring?

- Measure the exposure, AKA the dose
  - Historically the unique capability of the IH
  - Quantify the dose
  - Determine significance of exposure

- Determine extent of exposure
  - Exposure within a process
  - Exposures across an industry
  - Exposures across multiple workplaces

- Characterize risk
  - Balance hazard data against exposure

Risk Mamagement of Engineered Nanoparticles:

The Simple Questions

Are they hazardous?

Can they be measured?

Can they be controlled?

Hazard Identification
"Is there reason to believe this could be harmful?"

Exposure Assessment
"Will there be exposure in real-world conditions?"

Risk Characterization
"Is substance hazardous *and* will there be exposure?"

Risk Management
"Develop procedures to minimize exposures"

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Risk Management

Determine hazard

Hazard Identification
"Is there reason to believe this could be harmful?"

Exposure Assessment
"Will there be exposure in real-world conditions?"

Risk Characterization
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Material Characterization

- Engineered Nanoparticles: General Properties
  - More reactive, greater surface area
  - Shape and size drive behavior
  - Very mobile, extent of agglomeration varies
  - Not always pure
- Dry processes are higher concern
- What does the literature tell us

<u>Are any trends being seen?</u>

Pulmonary Toxicity Studies- Carbon Nanotubes

Aspiration of SWCNT resulted in:

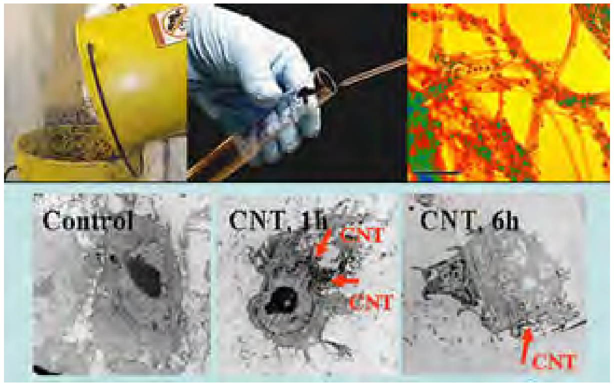
- Rapid but transient inflammation and damage
- Granulomas and fibrosis at deposition sites of large agglomerates of SWCNT
- Rapid and progressive interstitial fibrosis at deposition sites of dispersed SWCNT
- Results were verified with inhalation study

Message:

•SWCNTs more fibrogenic than an equal mass of ultrafine carbon black or fine quartz.

•Doses approximated exposure at the PEL for graphite (5 mg/m3) for 20 days

Message: The PEL for the 'large' form of a material may not be a good guide for the nano form.



Graphics courtesy of Andrew Maynard and Anna Shvedova

Key Elements of a Risk Management Program to Protect Nanotechnology Workers

Measuring the Dose: the Industrial Hygiene Challenge → Exposure Assessment

Hazard Identification

Identify materials and classify by their hazards: chemical or physical

Exposure Assessment

Identify tasks and workers who may be exposed and make measurements

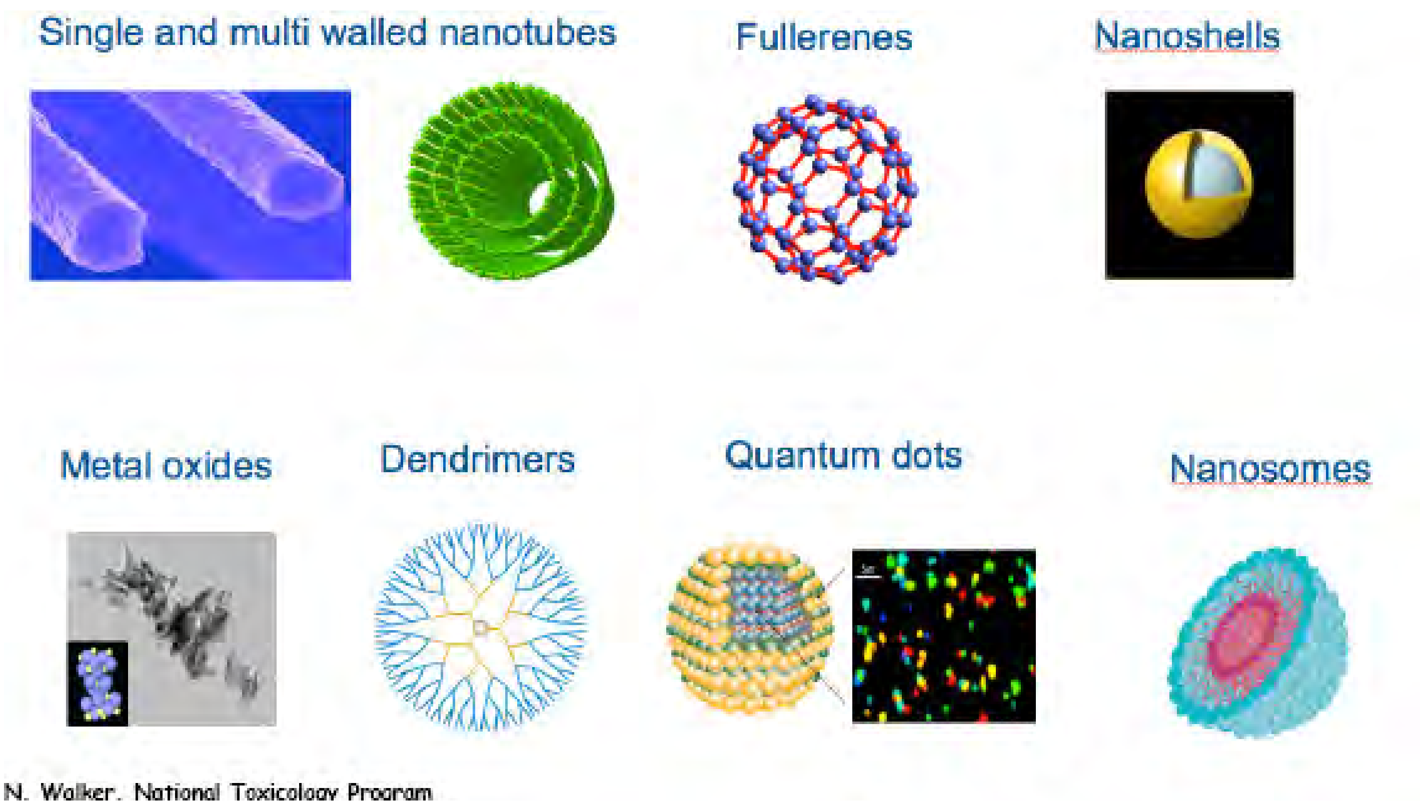
Risk Characterization

Connect what is known about hazard with exposure experience

Risk Management

Develop and implement a control plan with periodic checks

Nanoparticles: Many shapes, many chemistries



Not all nanoparticles are the same

What is different for the Industrial Hygienist?

- Focus is the unbound nanoparticle
- Physical, chemical and biological behavior is dictated by different parameters:

Size, Shape, Surface Area, Surface Activity

- Different from historical perspective of mass and chemical composition

"It's not simply mg/m^3 anymore"

Exposure Metrics

- Toxicology studies indicate *surface area* is a more appropriate metric
- Particle deposition is measured by *size*
- *Mass* is used as a general metric
- *Elemental* or compound analysis is used to speciate exposure or specific guidelines.

Which is most appropriate?

Exposure Metrics Proposed for Nanoparticles

- Mass: Nanoparticle mass is low
- Size distribution: Better indication of presence of nanoparticles, but not specific
- Number concentration: Helpful if possible in small size ranges (<500 nm)
- Surface area: Important metric in toxicology studies, but not specific

What is the best metric and where does one start?

Characterization of nanoparticles in workplaces

A suite of techniques is used …

Particle Number: A Starting Point

Condensation Particle Counter (CPC)

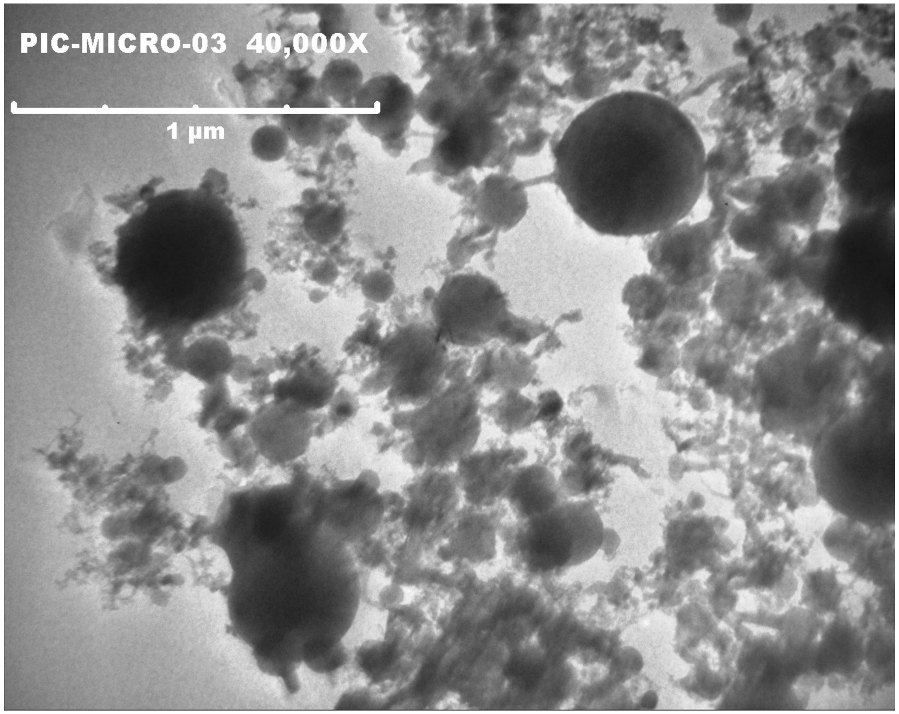
TSI 3007: particle size range of 10 nm to greater than 1.0 µm, a concentration range of 0 to 100,000 particles/cm3.

Optical Particle Counter/Sizer (OPC)

ART Instruments (ARTI): 300 nm to >10 um in six sizes simultaneously

Correlate Simple and Complex Measurements

Starting Point

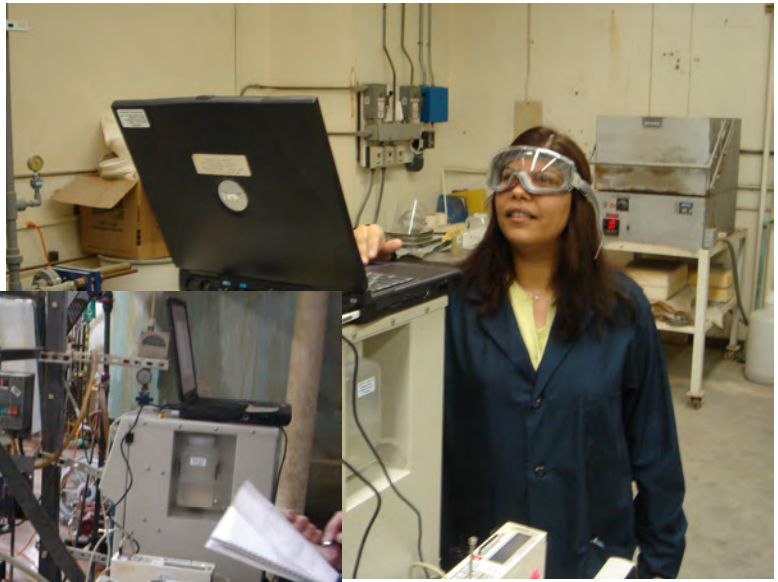


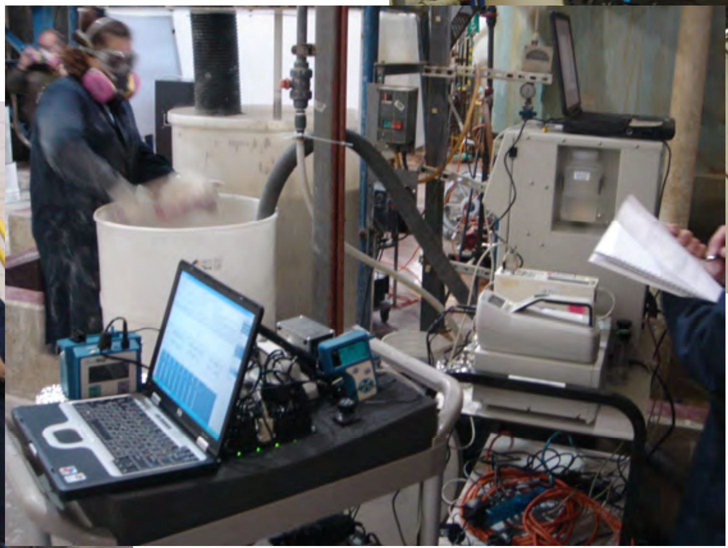
Mass, Size Distribution, Surface Area, Etc.

TEM analysis of aerosol

The Hard Way

In the Plant





Other sources of ultrafine aerosols exist in the workplace and can affect measurements

Key Elements of a Risk Management Program to Protect Nanotechnology Workers

Hazard Identification
"Is there reason to believe this could be harmful?"

Exposure Assessment
"Will there be exposure in real-world conditions?"

Interpretation

Risk Characterization
"Is substance hazardous *and* will there be exposure?"

Risk Management
"Develop procedures to minimize exposures"

Adapted from Gibbs, 2006

Examples of NIOSH Field Investigations

Type of Facility	Type of Particle, Morphology	Size of Particle	Range of "Potential" Exposure Concentrations (Duration of Task)
University Research lab	Carbon Nanofibers	Approx. 100 nm diameter, 1-10 microns long	60-90 µg/m^3
Metal Oxide Manufacturer	TiO_2, Lithium Titanate, powder	100-200 nm	<100 nm: 1.4 µg/m^3 (TiO_2) Total dust: 4-149 µg/m^3 (TiO_2) <100 nm: ND (Li) Total dust: ND -3 µg/m^3 (Li)
Manufacturer	Carbon Nanofibers	Approx. 100 nm diameter, 1-10 microns long	15 - 1800 µg/m^3
Research and Development lab	Quantum Dots, spheres	2 -8 nm	ND
Metal Oxide Manufacturer	Manganese, Silver, Nickel, Cobalt, Iron oxides, spheres	8 -50 nm	67 - 3619 µg/m^3
Research and Development lab (Pilot-Scale)	Aluminum, spheres	50 – 100 nm	40 - 276 µg/m^3
Research and Development lab	Elemental Metals - Silver, Copper, TiO_2	15 – 40 nm	ND
Filter Media Manufacturer	Nylon 6 Nanofiber	70 - 300 nm diameter, continuous length	ND

Risk Management

Hazard Identification

"Is there reason to believe this could be harmful?"

Exposure Assessment

"Will there be exposure in real-world conditions?"

Risk Characterization

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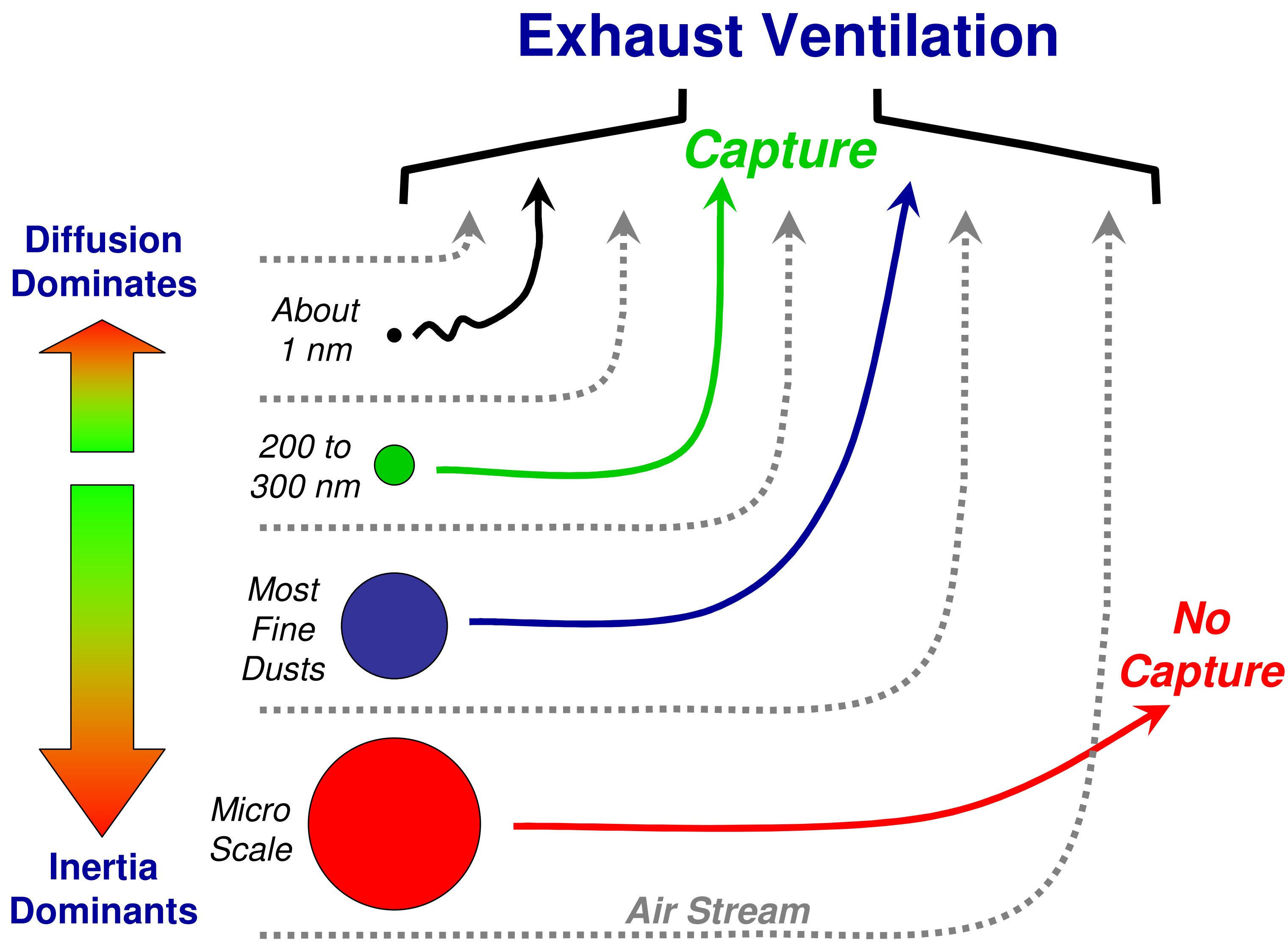
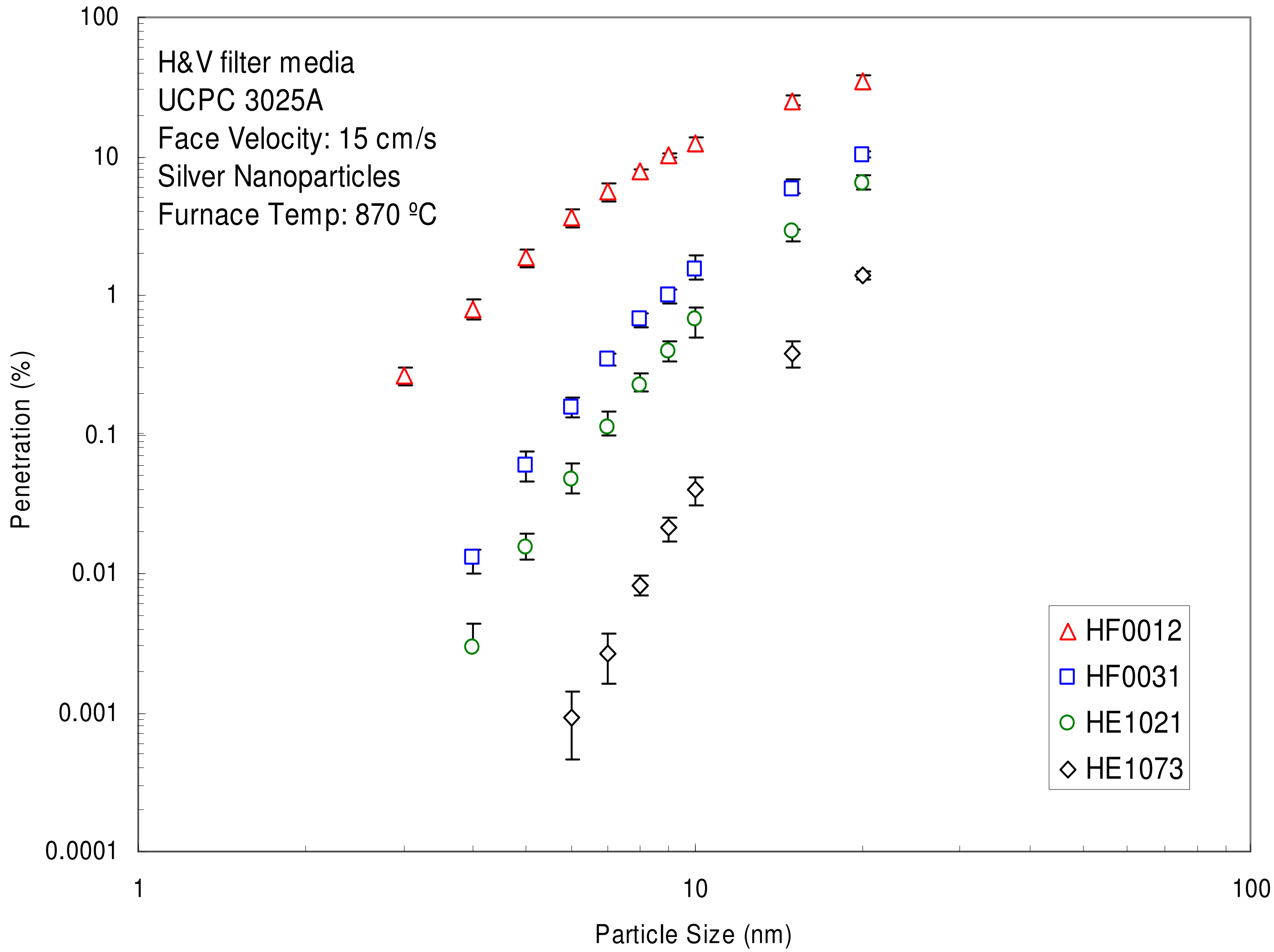
Control

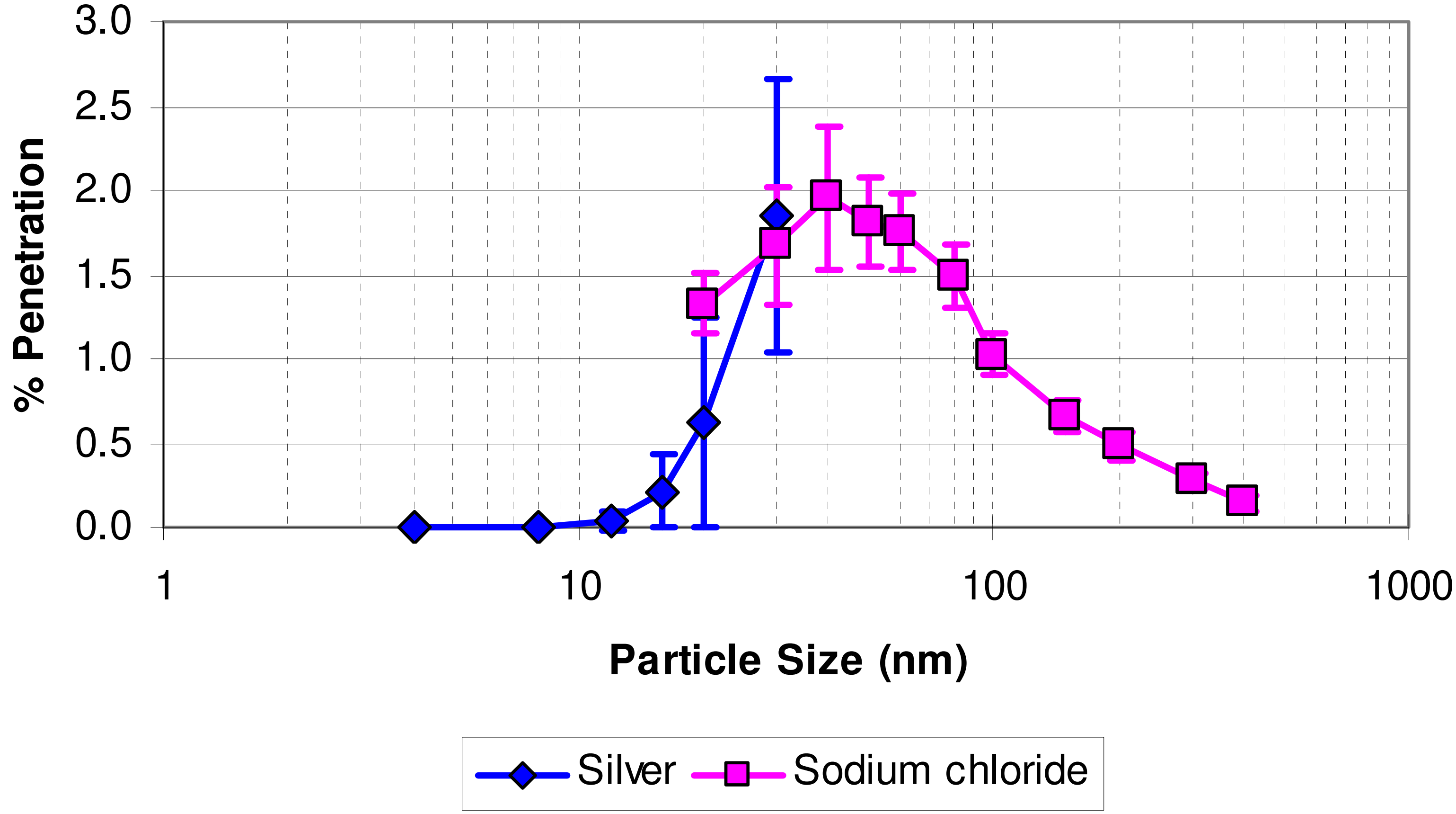
Conventional Controls Should Work



Nanoparticle penetration for H&V filter media (Vf=15 cm/s)



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

Controls have been applied in research and pilot development work

Applying Conventional Controls

Courtesy of M.M. Methner

Some Basic Findings from Field Studies

- “Wet” processing is a good way to contain nanomaterials once made
- Research labs do have emissions/exposures
- Containment and local controls works, but must be selected with good input
- Work practices play a major role
- Maintenance tasks must be included in any assessment

Research Activities and Findings

- Engineered nanoparticles have a higher degree of biological hazard: lung fibrosis and translocation to other organs
- Measurement methods: mass, particle number and surface area are being evaluated
- HEPA filtration is effective and respirators should be protective
- Protective garments being evaluated

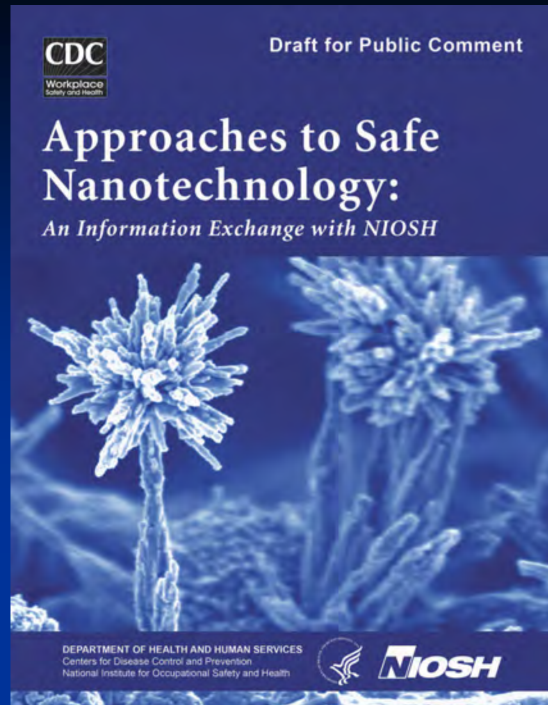
Assessing the Nanoproduct Life Cycle

What we know

- Some potential hazard
- Some exposure occurs
- Some risk may exist
- Nanoparticles can be measured
- Nanoparticles can be controlled
- Filters and respirators should protect
- There are no specific exposure limits
- There is no recommended occupational health surveillance guidance

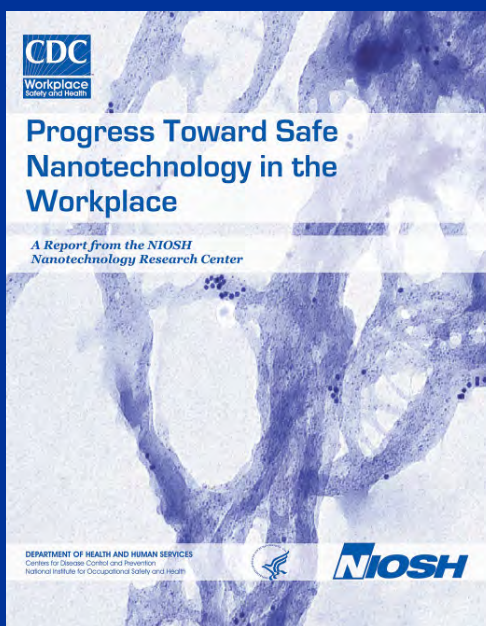
What we don't know

- Nature and extent of hazard
- Nature and extent of exposure
- Nature and extent of risk
- What measures to use
- Limitations of controls
- Limitations of protection
- What limits are appropriate
- Content of surveillance



Recommendations from NIOSH

- Summary of issues
- Approaches to consider
- Basic Guidance
- Updated as new information comes on-line
- Input requested



- Research progress in 10 key areas
- Continuing project plans
- Opportunities for collaboration

www.cdc.gov/niosh/topics/nanotech

Thank You

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