Nanotechnology
Overview and Relevance to Occupational Health

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NASA, Oct 21st 2005
Nanotechnology and Potential Health Impact

ETC Group Occasional paper Series. Volume 7 No. 1. April 2003
Nanotechnology
Science Fiction or Science Fact?

Imagine…

A material where strength is governed by atomic bonds…

… that can be woven into super-strong strands and ropes…

… and used to build an elevator to space!

Nanotechnology is turning fiction to reality…

www.liftpart.com

Countdown to Lift: April 12, 2018
4891 days, 10 hours, 33 minutes, 42 seconds

Single Walled Carbon nanotubes
Nanotechnology

- **Definition**
  - Development/engineering of new devices and materials which demonstrate unique properties associated with structures on a nanometer length-scale
  - Nanometer scale: less than ~100 nm

- **Includes:**
  - Engineered nano-scale surface layers
  - Engineered nano-scale structures (discrete or heterogeneous)
  - Engineered nano-scale devices
From Micro to Nano..
“Nano” is less than 100 nm
Unique Structures and Morphologies
Single Walled Carbon Nanotubes

- 1.4 nm in diameter
- Micrometers in length
- Unique physical, chemical and electronic properties

Transmission Electron Microscopy

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Unique Quantum Properties
Quantum Dots - particle size determines fluorescence

©Felice Frankel. web.mit.edu/felicef. This image is part of the larger “Envisioning Science Project” at MIT

Smaller particles

Larger particles
Unique Devices
‘Smart’ multifunctional nanoparticles

Raoul Kopelman and Martin Philbert, University of Michigan

nano.cancer.gov
Nanotechnology Investment and Impact
Global R&D Investment in 2004

$4.6 billion
$3.8 billion
$0.2 billion

Nanotechnology Investment and Impact
Global forecast of products sold incorporating nanotechnology

- **2004:** Selective deployments proliferate
- **2005 - 2009:** Commercial breakthroughs open market
- **2010 - 2014:** Nanotechnology becomes commonplace

Nanotechnology is ‘Now’
Selected consumer products

Nanoclay Composite

Easton CNT is Real Nanotechnology

Carbon Nanotube Composite

Nanosilica Composite

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Defining the Issue
Nanotechnology and Occupational Health

• **Nanotechnology - The Motivation**
  • Purposely engineered nanostructured materials and devices demonstrate new, unique and non-scalable properties and behavior

• **Sustainable Nanotechnology - The Challenge**
  • Does the nature of engineered nanostructured materials and devices present new safety and health risks?
  • How can the benefits of nanotechnology be realized while proactively minimizing the potential risk?
Concern Over the Potential Impact of Nanotechnology

ETC Group 2003

VDI (Germany) 2004

SwissRe 2004

Environmental Health Perspectives 2004

Royal Society 2004

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Potential Health Impact
What makes ‘nano’ different?

Influence of structure on potential health impact

Physical Structure

Low

High

Size
Shape
Surface Area
Surface Activity
Nano-Structure

Conventional Understanding

Macro-Materials
Liquids
Gases & Vapors

Unconventional Understanding

Nano-Materials & Devices

Mass
Composition

Compositional Structure

Low

High
TiO2 Instillation in Rats
Oberdörster et al. (2000)

TiO2 Instillation in Rats - Surface Area
Oberdörster et al. (2000)

Significance of Surface Activity
Comparison between low and high activity materials

Particle Size
Translocation Following Inhalation - Lungs to Liver

Fraction of inhaled insoluble $^{192}$Ir translocating to liver in rats

Particle Size
Translocation Following Inhalation - Upper airways to brain


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Significance of Morphology
Single Walled Carbon Nanotubes

Transmission Electron Microscope image of purified single walled carbon nanotube particles

Allotropes of carbon
- Carbon support film
- Open structured particles
- Closed structured particles

Ku, Evans, Ramsey and Maynard, in Shvedova et al. (2005)
**Single Walled Carbon Nanotubes**

Tissue thickening in mice - Pharyngeal aspiration

![Graph showing average tissue thickness vs instilled dose](image)

- **Granulomatous Cellular Tissue**
- **Granulomatous Connective Tissue**
- **Alveolar Connective Tissue**

**Instilled Dose (μg/mouse)**

- 0
- 10
- 20
- 40

**Average Tissue Thickness (μm)**

- 0
- 0.5
- 1
- 1.5
- 2
- 2.5
- 3

**Proximal region of lung**

Visible SWCNT clumps

**Distal region of lung**

No SWCNT visible

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Addressing Occupational Impact

Exposure Routes → Exposure → Characterization

- Dose
  - Education
  - Risk
    - Control
      - Reduced Impact
        - Knowledge Level
          - Poor
          - Good

- Health Effects
  - Toxicity
Setting Boundaries
Engineered nanomaterials which potentially present new challenges

- Criteria:
  - Nanomaterials capable of entering or interacting with the body
  - Nanomaterials which potentially exhibit nanostructure-dependent biological activity

- Nanoparticles
  Simple, complex, “smart”. Aerosols, powders, suspensions, slurries

- Agglomerates
  or aggregates of nanoparticles

- Aerosolized suspensions
  Including slurries and solutions of nanomaterials

- Commination
  Aerosols from grinding, cutting, machining nanomaterials

- Degredation/Failure
  Aerosols and suspensions resulting from degradation and failure of nanomaterials

- Unintentional use
  Potential exposure from unanticipated/unintentional use
Monitoring Nanoscale Aerosol Exposures

Options

- Adapt current mass-based approaches
  - Continuity with the past
  - Sensitivity and relevance issues

- Measure size distribution
  - Provides a lot of information
  - Impractical in many instances

- Monitor number concentration
  - Relatively simple
  - Difficult to differentiate between process-related and background aerosols
  - Relevance?

- Monitor aerosol surface area concentration
  - Relevant for some materials. Is this achievable?
Aerosol Surface-Area Measurement
Using attachment rate

Charge on \( \propto \) Aerosol Surface Area

DC2000 CE Diffusion Charger

EcoChem

Electrometer

Ions

Aerosol Surface-Area Measurement Using attachment rate
Comparison of Measurement Methods
Monodisperse particles < 100 nm, fractal-like

Ku and Maynard, J. Aerosol Sci (in press)
Emerging Measurement Technologies
Deposited Surface Area

Wilson et al. (2004)

Nanoparticle Surface Area Monitor
www.tsi.com

Diffusion Charger
www.ecochem.biz

Particle diameter / nm

Size Distribution (Surface)
Alveolar deposition
 Deposited Surface Area
Handling Nanotube Material

Unprocessed single walled nanotube material
Laboratory Generation of Nanotube Aerosol

Agitation of unprocessed material in an airflow

Single Walled Carbon Nanotubes

Raw single walled carbon nanotube material.

- Nanotubes
- Nanoropes
- Catalyst particles
- Non-tubular carbon
Nanotube Aerosol Characterization

- Physical/Chemical Characteristics?
- Discrete carbon nanotubes or nanoropes?
- Transition metal catalyst particles?
- Non-tubular carbon?
Aerosol Characterization

‘Active specific surface area’ measurements

Differential Mobility Analysis

- Same mobility diameter
- Measure surface area
- Specific surface area

Aerosol Particle Mass Analysis

- Electrostatic deposition
- Inertial deposition
- Measure mass

-3000 rpm

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Aerosol Characterization

‘Active’ specific surface area

Maynard, Ku, Stolzenburg, Emery, McMurry
Impact of Engineered Nanomaterials
Global initiatives

- Europe
- Asia
- USA
- Partnerships
- Academia
- Industry
- Non-Government Organizations

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Goal 4: Support responsible development of nanotechnology:

- Environmental, health and safety implications
- Ethical, legal and all other societal issues

Program Component Area 7: Societal Dimensions

- Environmental, health and safety research
- Education
- Broad societal implications

www.nano.gov
Working with Engineered Nanomaterials
NIOSH

The National Institute for Occupational Safety and Health (NIOSH) is pleased to present the Strategic Plan for NIOSH Nanotechnology Research: Filling the Knowledge Gaps, September 2005. The strategic plan provides a guide for building a research effort capable of responding to the challenges of this emerging technology. It represents a timely research agenda and will evolve as new information becomes available and a more thorough scientific understanding about nanotechnology develops. The strategic plan describes a multi-dimensional research agenda. It addresses what NIOSH is doing internally and externally to lead the occupational safety and health community collaboratively in nanotechnology research. The strategic plan (full text) can be downloaded for a complete description of NIOSH’s activities in the area of nanotechnology. Printer Friendly Version (PDF 422 kb, 69 pages) version of the full text.

www.cdc.gov/niosh/topics/nanotech/strat_plan.html
Working with Engineered Nanomaterials
NIOSH

Approaches to Safe Nanotechnology: An Information Exchange with NIOSH

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Director's Message

The field of nanotechnology is advancing rapidly and will likely revolutionize the global industry. As with any new technology, we are faced with many unknowns; all of which raise questions concerning occupational safety and health. The National Institute for Occupational Safety and Health (NIOSH) is committed to ensuring worker protection as nanotechnology develops.

NIOSH has developed the document Approaches to Safe Nanotechnology: An Information Exchange with NIOSH to raise awareness of potential safety and health concerns from exposure to nanomaterials. The document also addresses current and future research needs essential to understanding the potential risks that nanotechnology may have to workers.

It is imperative that the scientific community come together to advance our understanding of nanotechnology and its implications in the workplace. I invite you to participate in this process and encourage you to provide feedback, comments, or suggestions regarding the Approaches to Safe Nanotechnology document. I also encourage you to share any relevant information or experience pertaining to the field of nanotechnology.

As our knowledge grows, NIOSH plans to provide valuable guidance to the safe handling of nanoparticles and other safe approaches to nanotechnology. This will be an effort that evolves as the technology advances and our knowledge and experience grows.

www.cdc.gov/niosh/topics/nanotech/nano_exchange.html
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- **Goal**
  Ensure government and private sector address the risks as well as the benefits of nanotechnology

- **Budget**
  $3 million over 2 years

- **Programs**
  Meetings, research, polling, outreach

Created July 2005 in partnership with the Pew Charitable Trusts
www.nanotechproject.com
Project on Emerging Nanotechnologies
Current activities include…

- Database of federally funded research on environmental, safety and health implications
  - Providing an overview of research focuses and gaps

- Review of airborne nanomaterial exposure measurement requirements
  - Evaluating current capabilities and research/development needs

- Use of gene arrays in ecotoxicity screening
  - Developing rapid, cost-effective screening assays for early detection of potential issues

- Facilitating domestic and international partnerships
Summary

- Nanotechnology is a revolutionary technology
- Significant societal and economic benefits are anticipated
- Conventional risk management models are being challenged
- Successful development and implementation of nanotechnology will require an integrated approach to risk
- Global, interdisciplinary and cross-sector partnerships are essential to developing sustainable nanotechnologies
Looking to the Future
Moving beyond the health impact of ‘simple’ nanomaterials

Safety
“Unconventional” and unanticipated behavior

Complex nanoparticles and nano-devices
Moving beyond simple response mechanisms

Convergence
Revolutionary Health & Safety Challenges

www.liftport.com
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