NASA, Oct 21st 2005

Nanotechnology

Overview and Relevance to Occupational Health

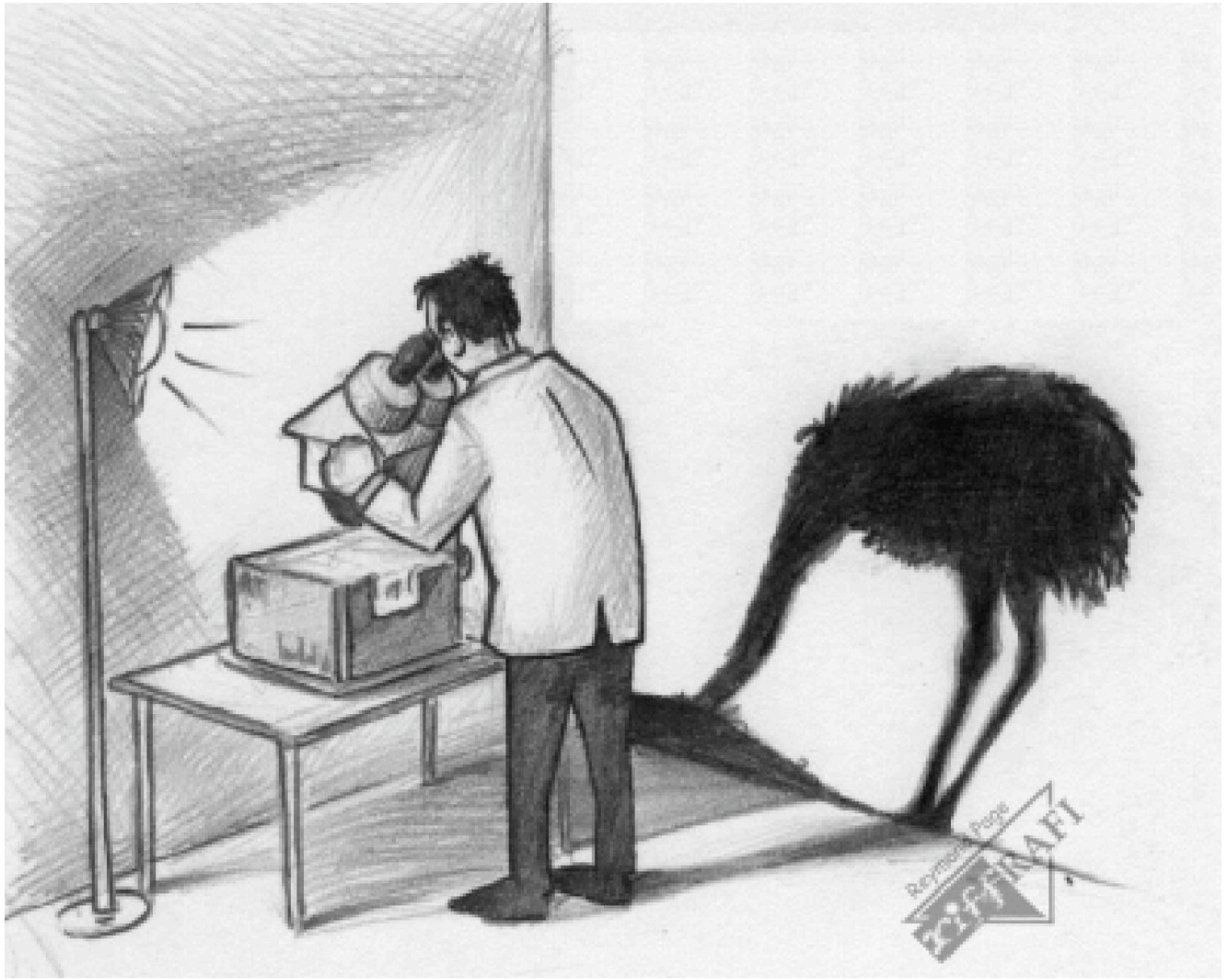
Andrew D. Maynard
Chief Science Advisor

Project on
Emerging Nanotechnologies
at the Woodrow Wilson International Center for Scholars

Woodrow Wilson International Center for Scholars

THE PEW CHARITABLE TRUSTS

Nanotechnology and Potential Health Impact

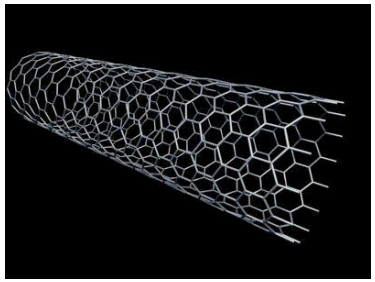


ETC Group Occasional paper Series. Volume 7 No. 1. April 2003

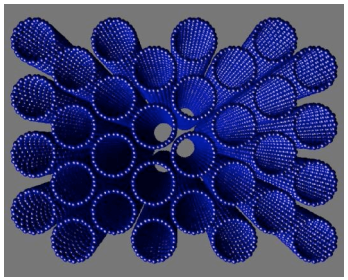
Nanotechnology

Science Fiction or Science Fact?

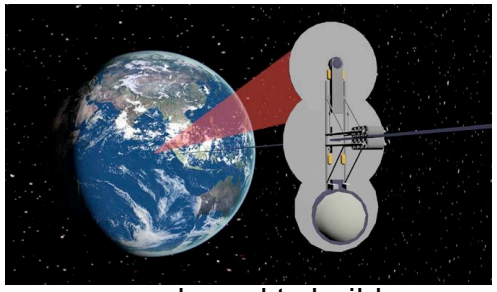
Imagine…



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…

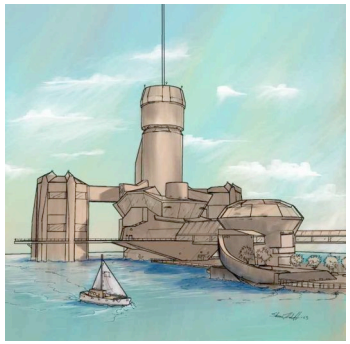
www.liftport.com

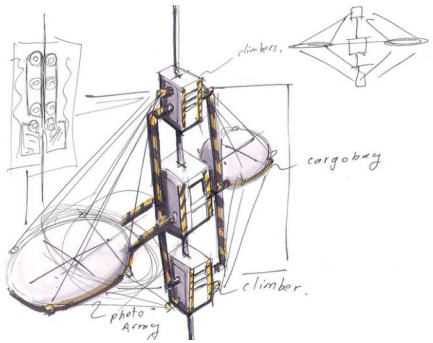
LIFTPORT GROUP

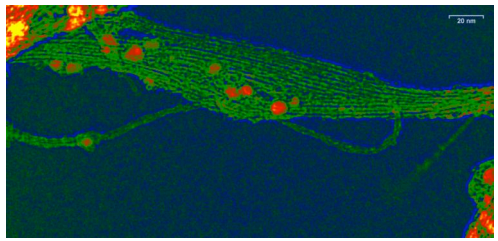
THE SPACE ELEVATOR COMPANIES™

Countdown to Lift: April 12, 2018

4891 days, 10 hours, 33 minutes, 42 seconds







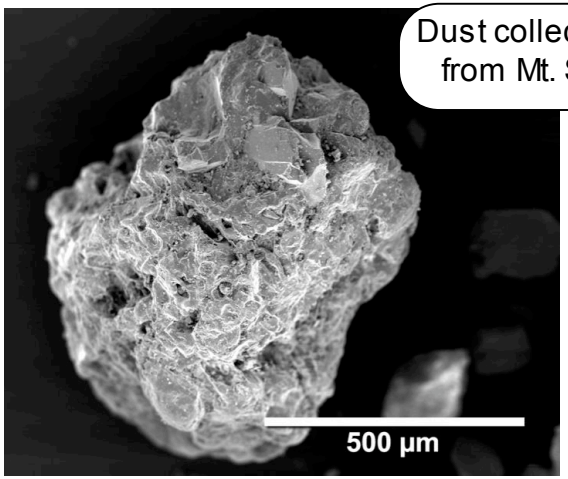
Single Walled Carbon nanotubes

Nanotechnology

- Definition
  - Development/engineering of new devices and materials which demonstrate unique properties asociated 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

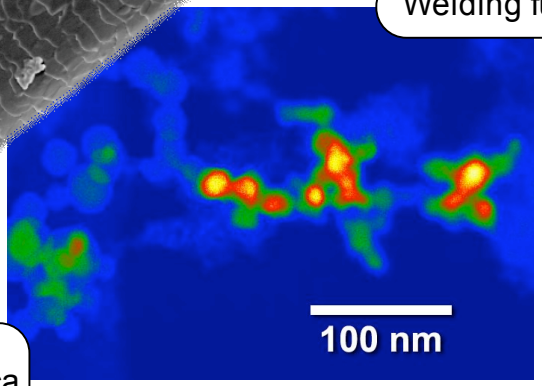


Dust collected 5 miles from Mt. St. Helens

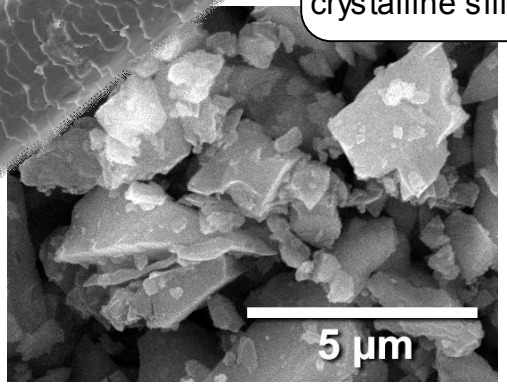
Human Hair

~70 µm

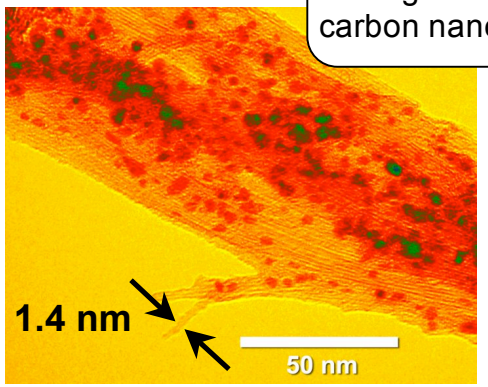
Welding fume



Respirable crystalline silica



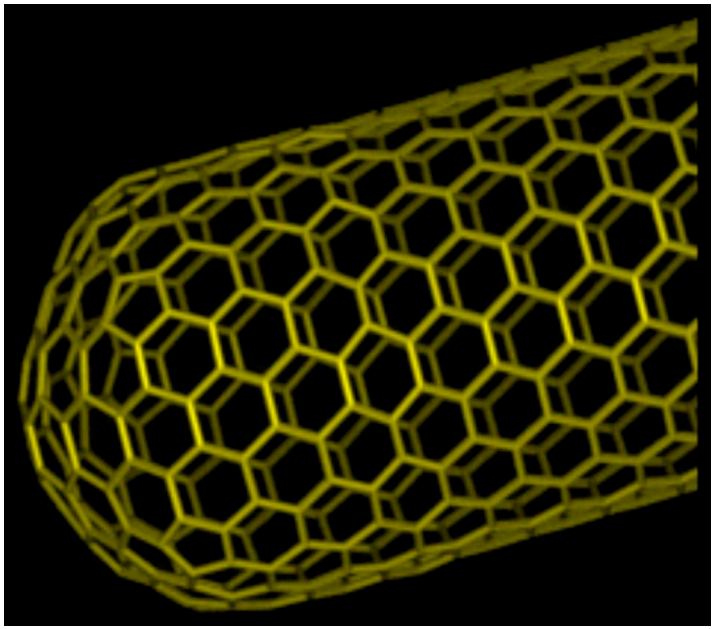
Single walled carbon nanotubes



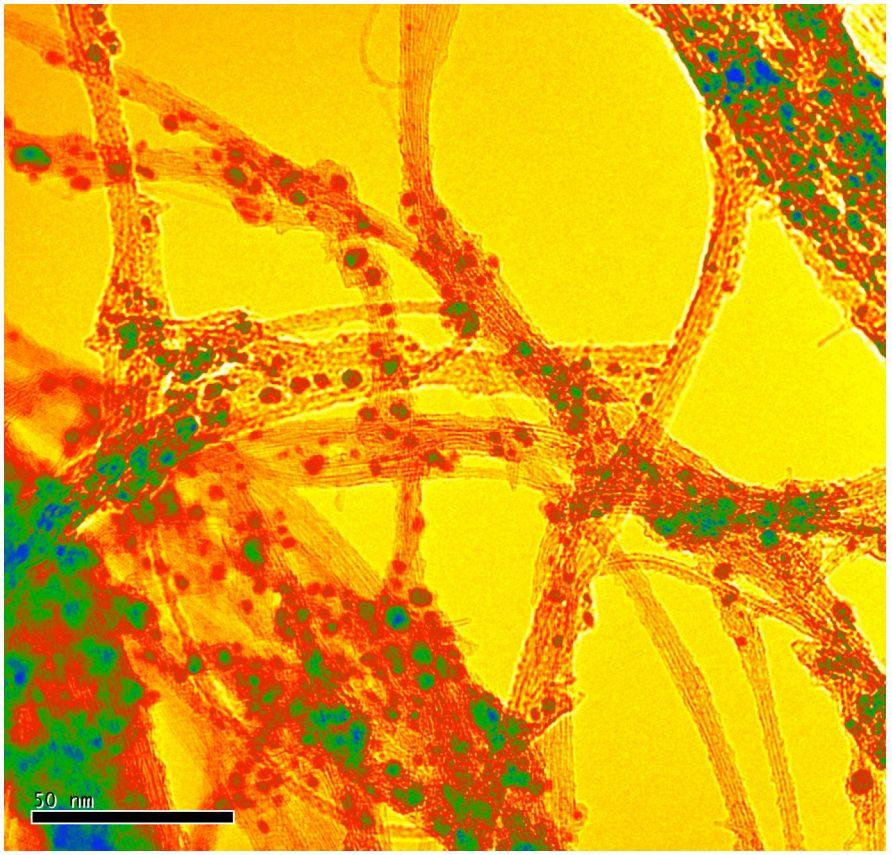
1 mm | 100 µm | 10 µm | 1 µm | 100 nm | 10 nm | 1 nm

Unique Structures and Morphologies

Single Walled Carbon Nanotubes



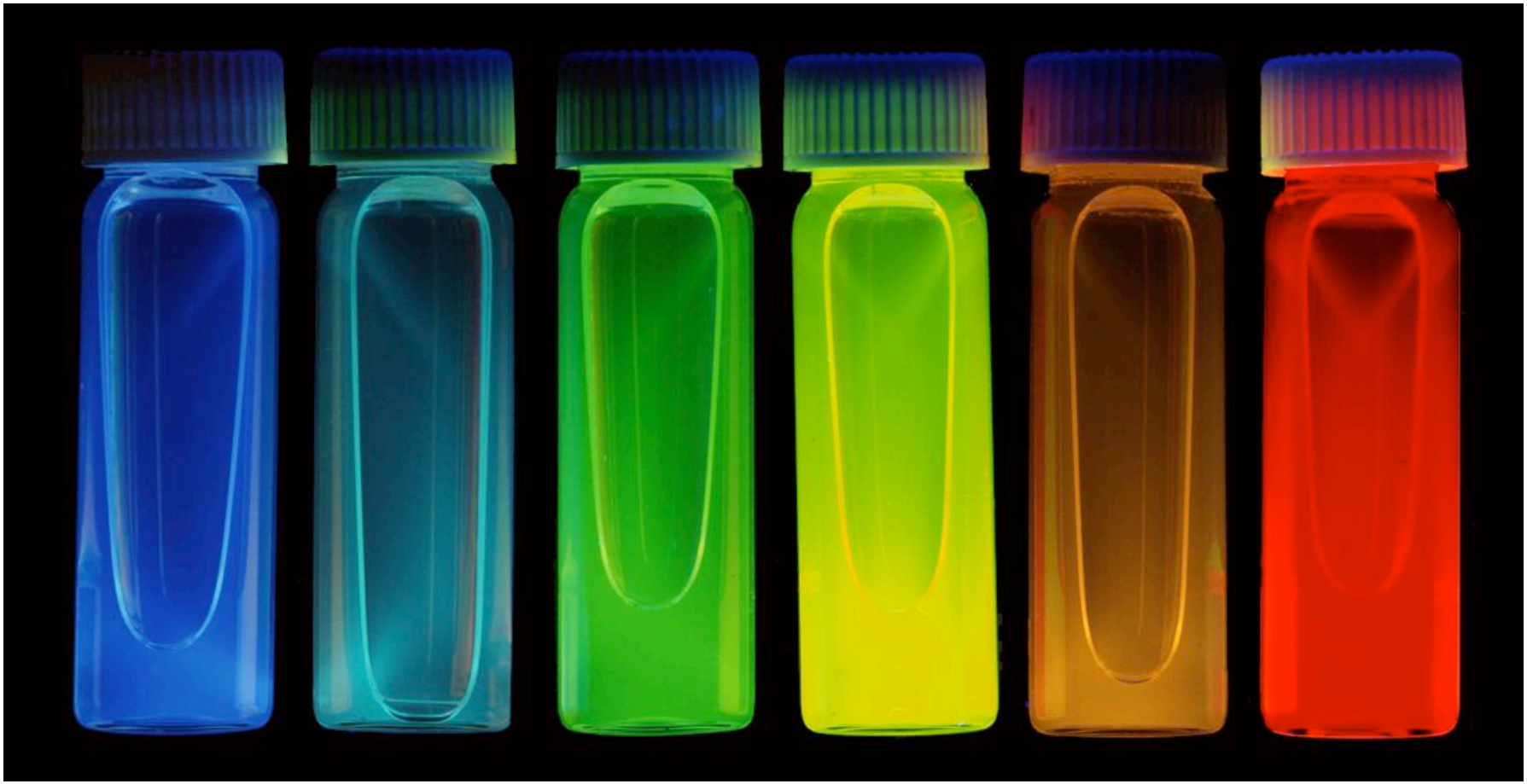
- 1.4 nm in diameter
- Micrometers in length
- Unique physical, chemical and electronic properties



Transmission Electron Microscopy

Unique Quantum Properties

Quantum Dots - particle size determines fluorescence

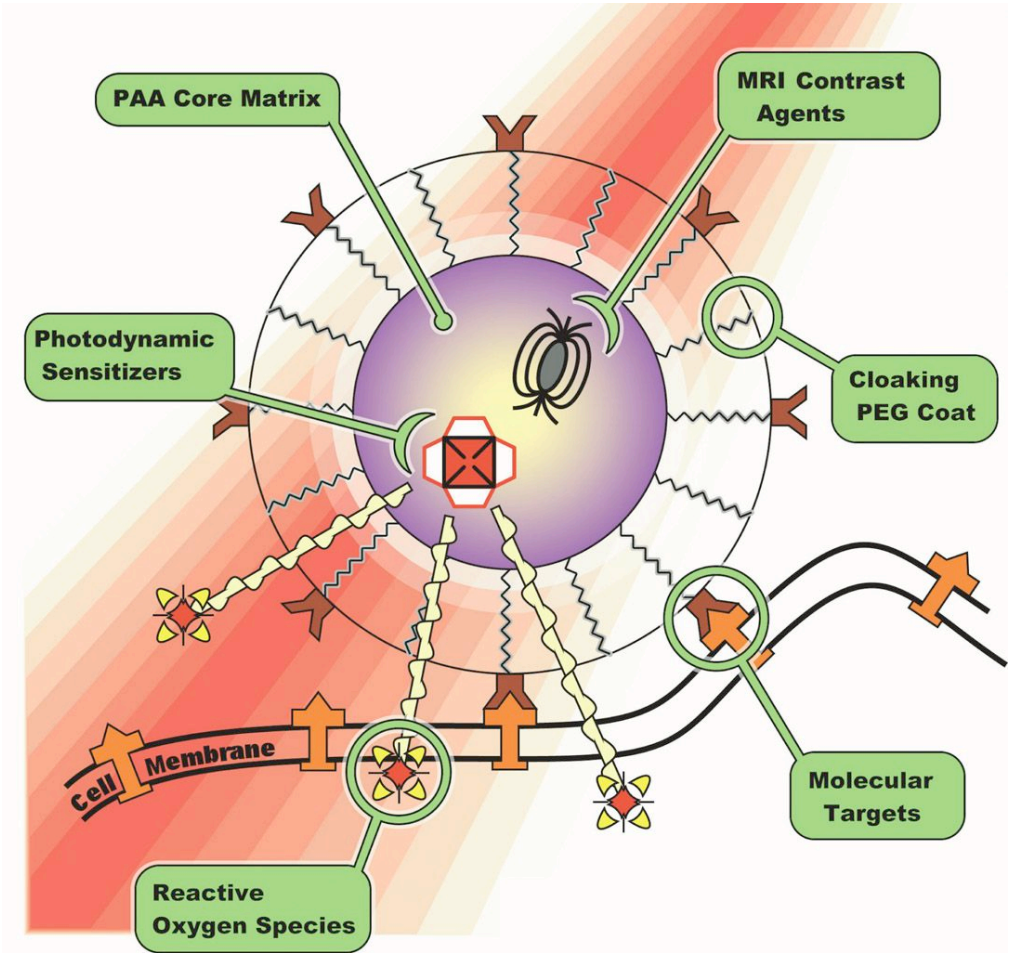


©Felice Frankel. web.mit.edu/felicef. This image is part of the larger "Envisioning Science Project" at MIT

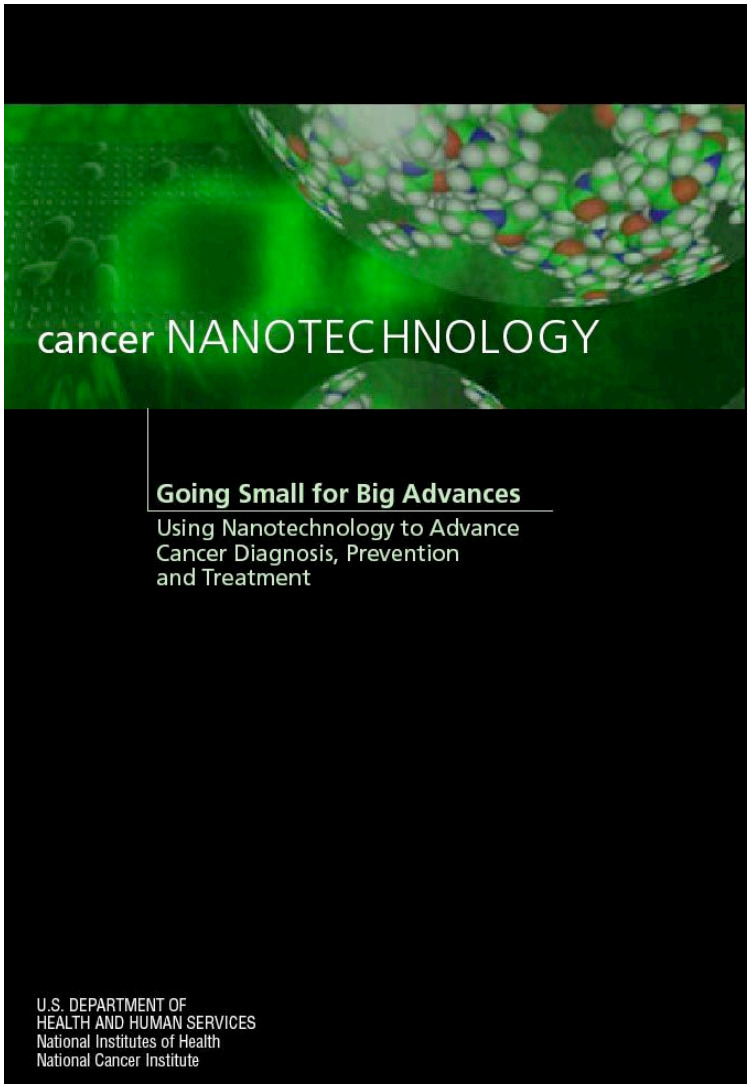
Smaller particles → Larger particles

Unique Devices

‘Smart’ multifunctional nanoparticles



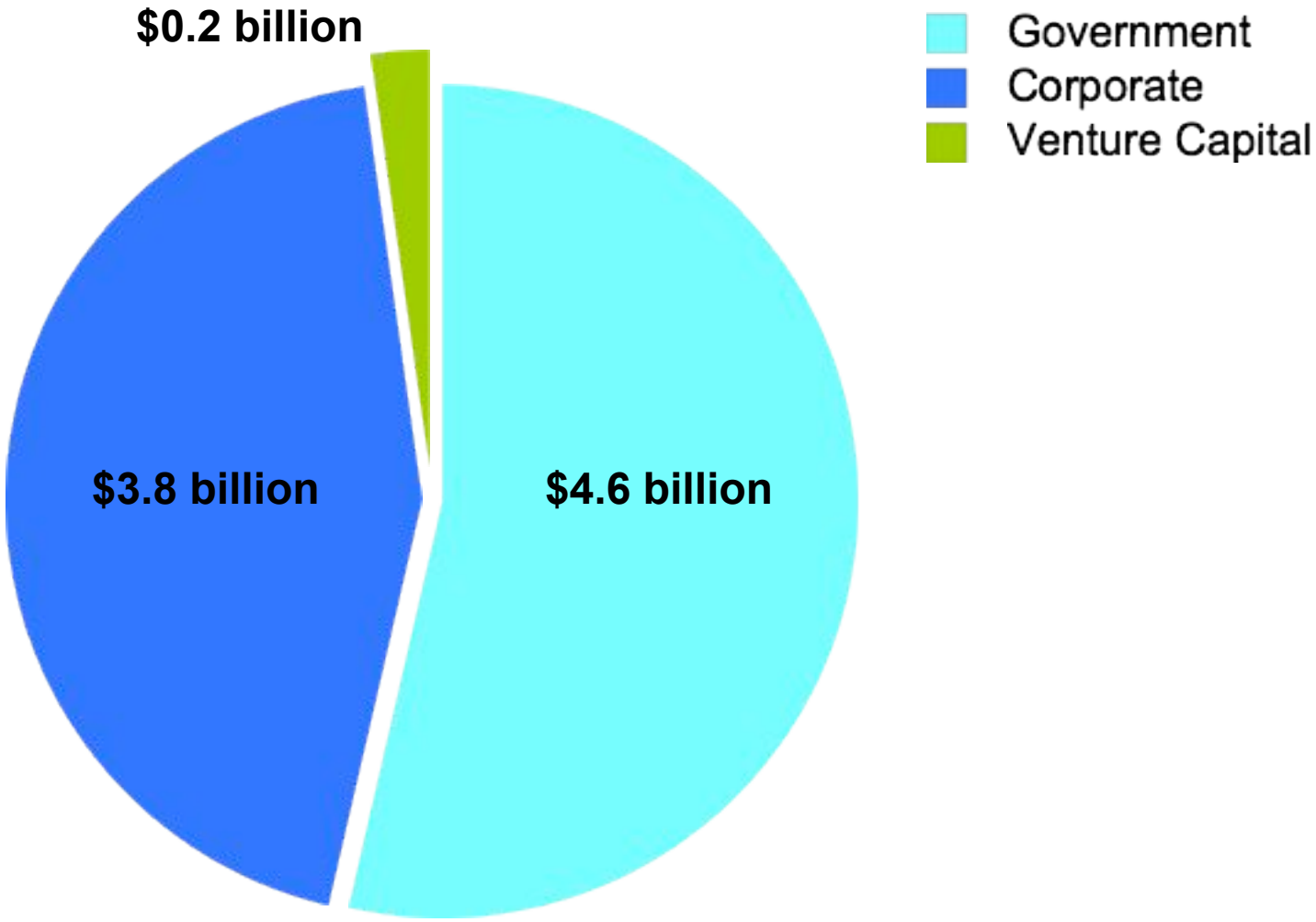
Raoul Kopelman and Martin Philbert, University of Michigan



nano.cancer.gov

Nanotechnology Investment and Impact

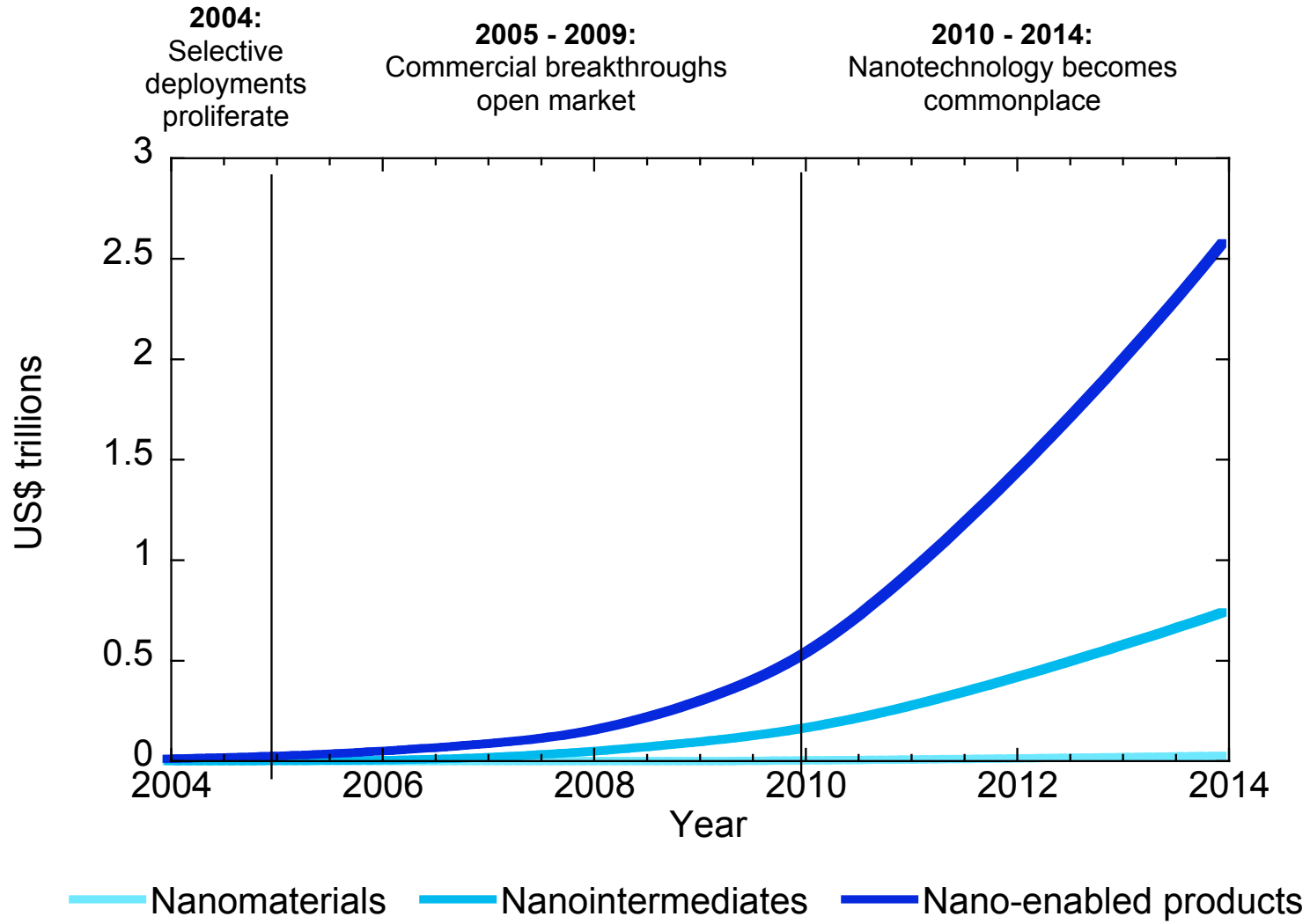
Global R&D Investment in 2004



Source: 2004 Lux Research Reference Study: "The Nanotechnology Report 2004"

Nanotechnology Investment and Impact

Global forecast of products sold incorporating nanotechnology



Source: 2004 Lux Research Report: "Sizing nanotechnology's value chain"

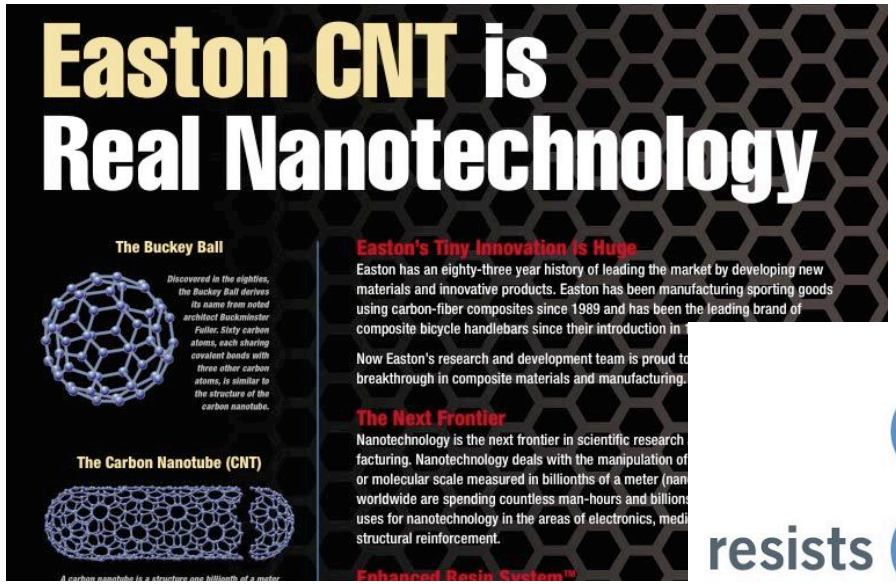
Nanotechnology is 'Now'

Selected consumer products

Nanoclay Composite

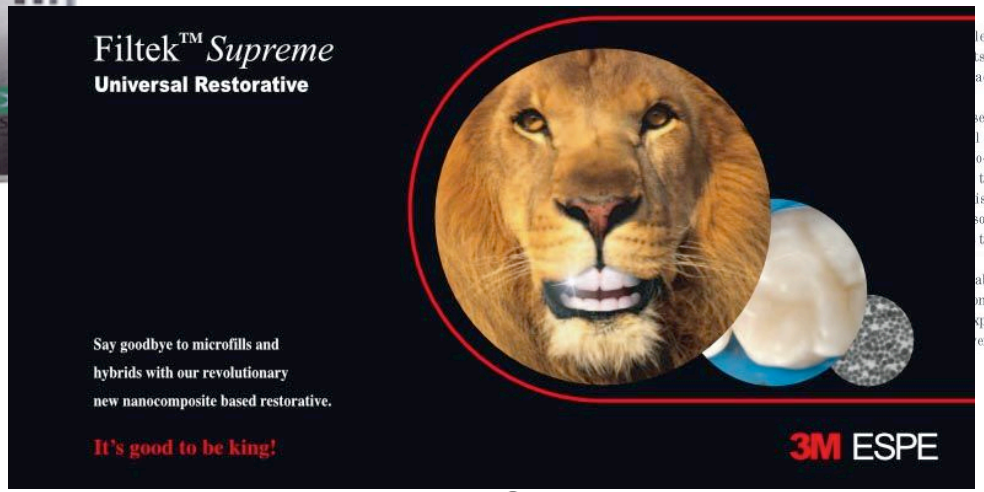
www.wilson.com

Carbon Nanotube Composite



www.eastonbike.com

Nanosilica Composite



www.3M.com

Nano fibers

www.nanotex.com

- **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

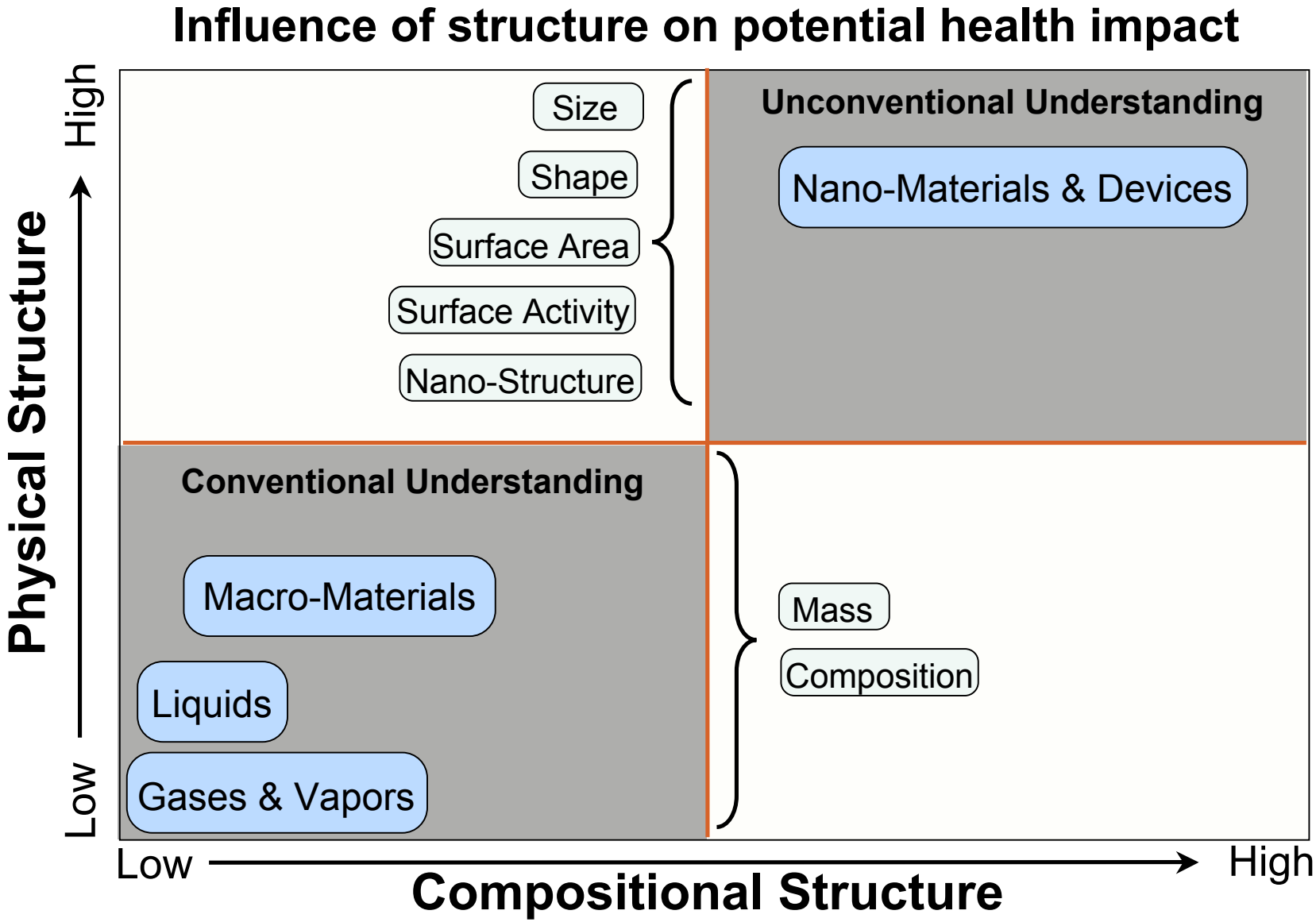
SwissRe 2004

Environmental Health Perspectives 2004

Royal Society 2004

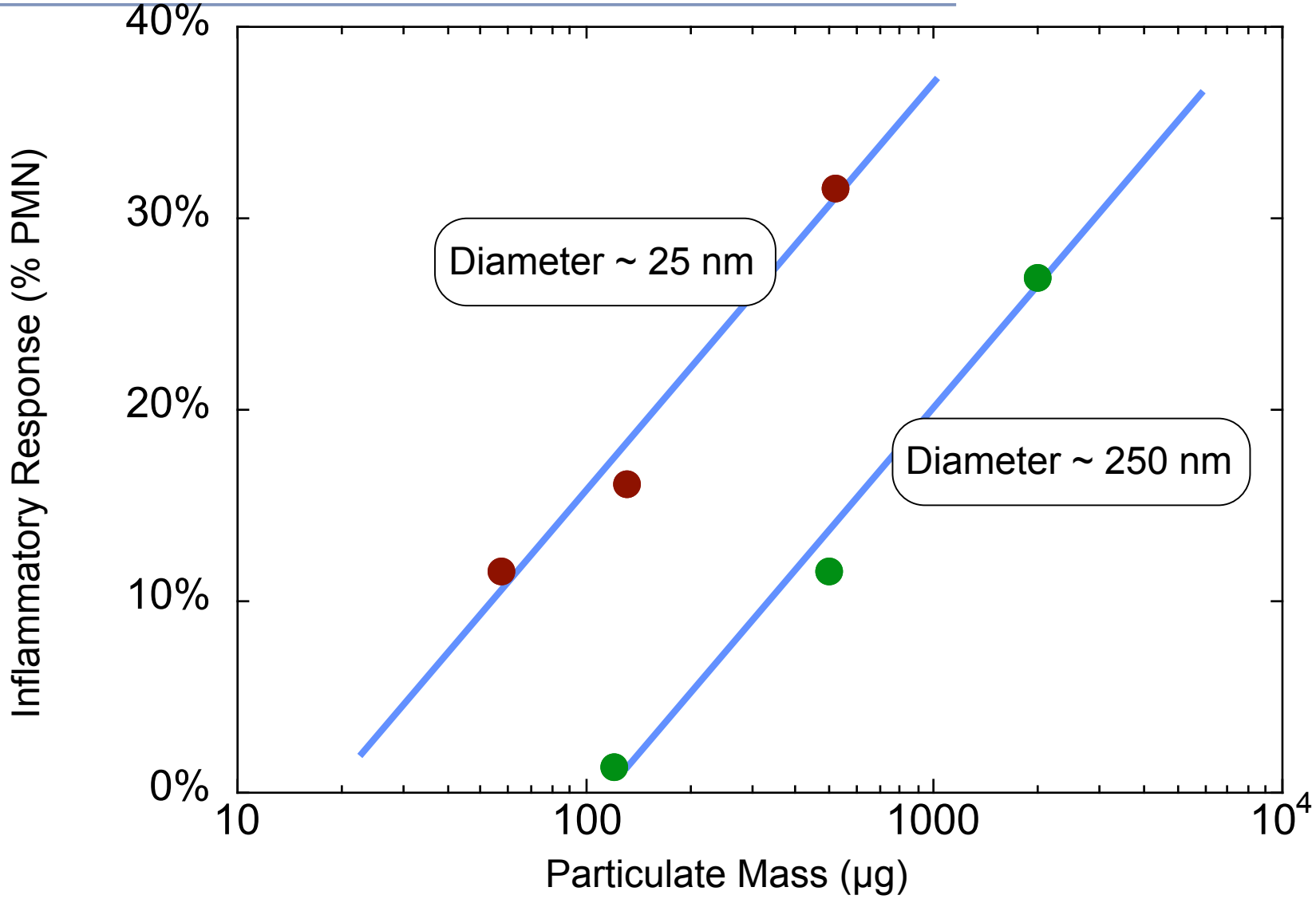
Potential Health Impact

What makes 'nano' different?



TiO2 Instillation in Rats

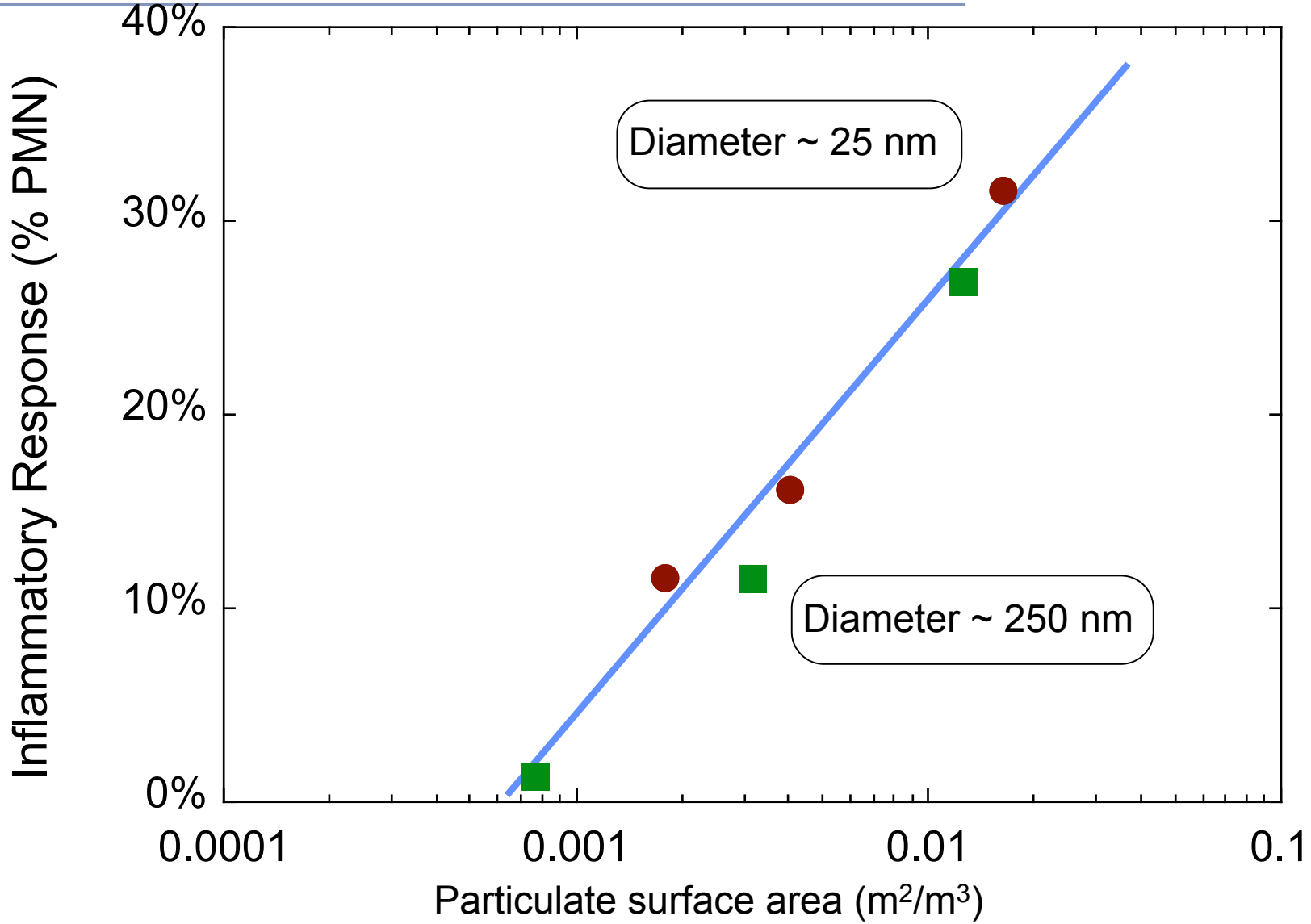
Oberdörster et al. (2000)



Oberdörster, G. (2000) *Phil. Trans. Roy. Soc. London Series A* **358**(1775): 2719-2740.

TiO2 Instillation in Rats - Surface Area

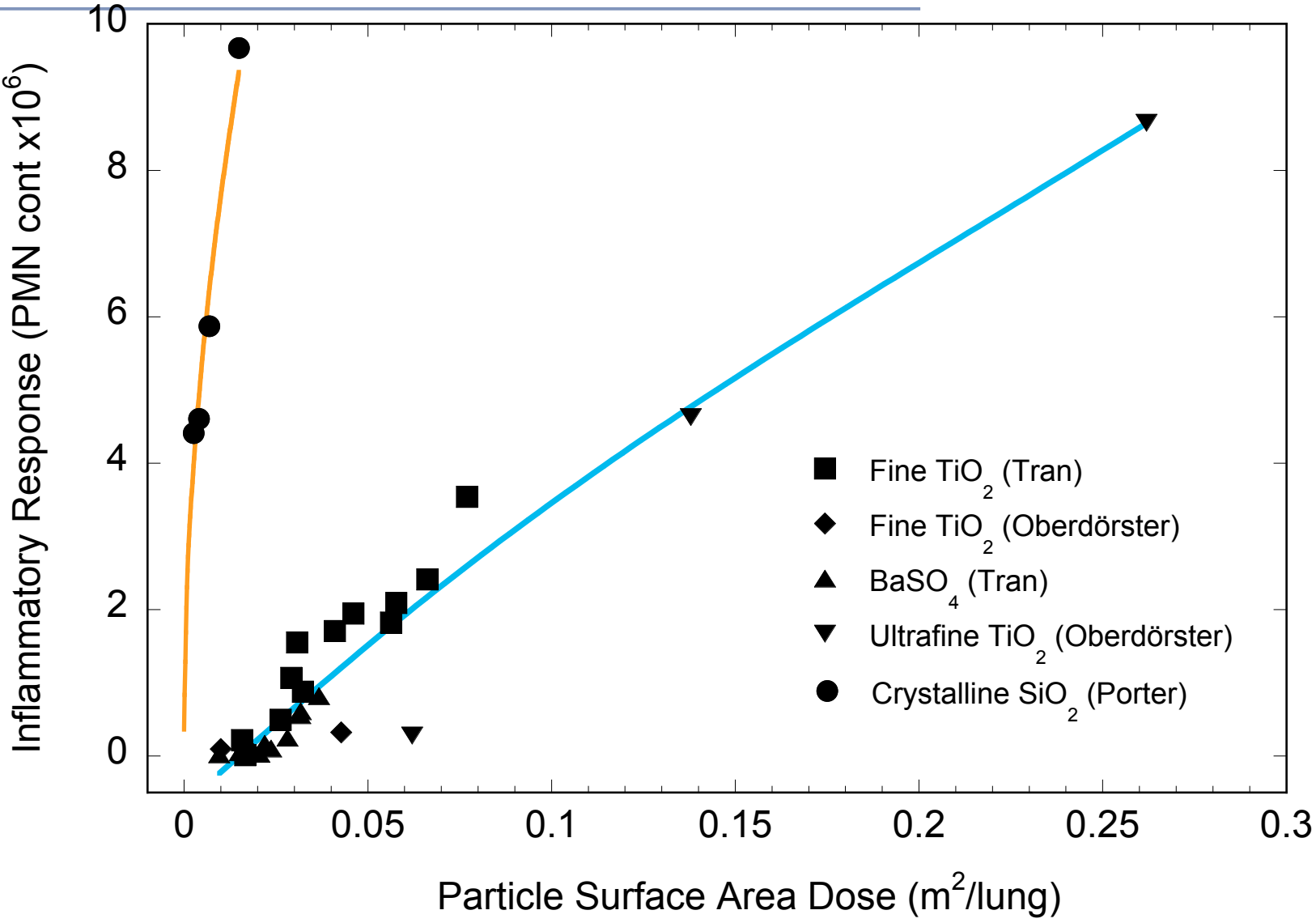
Oberdörster et al. (2000)



Oberdörster, G. (2000) *Phil. Trans. Roy. Soc. London Series A* **358**(1775): 2719-2740.

Significance of Surface Activity

Comparison between low and high activity materials

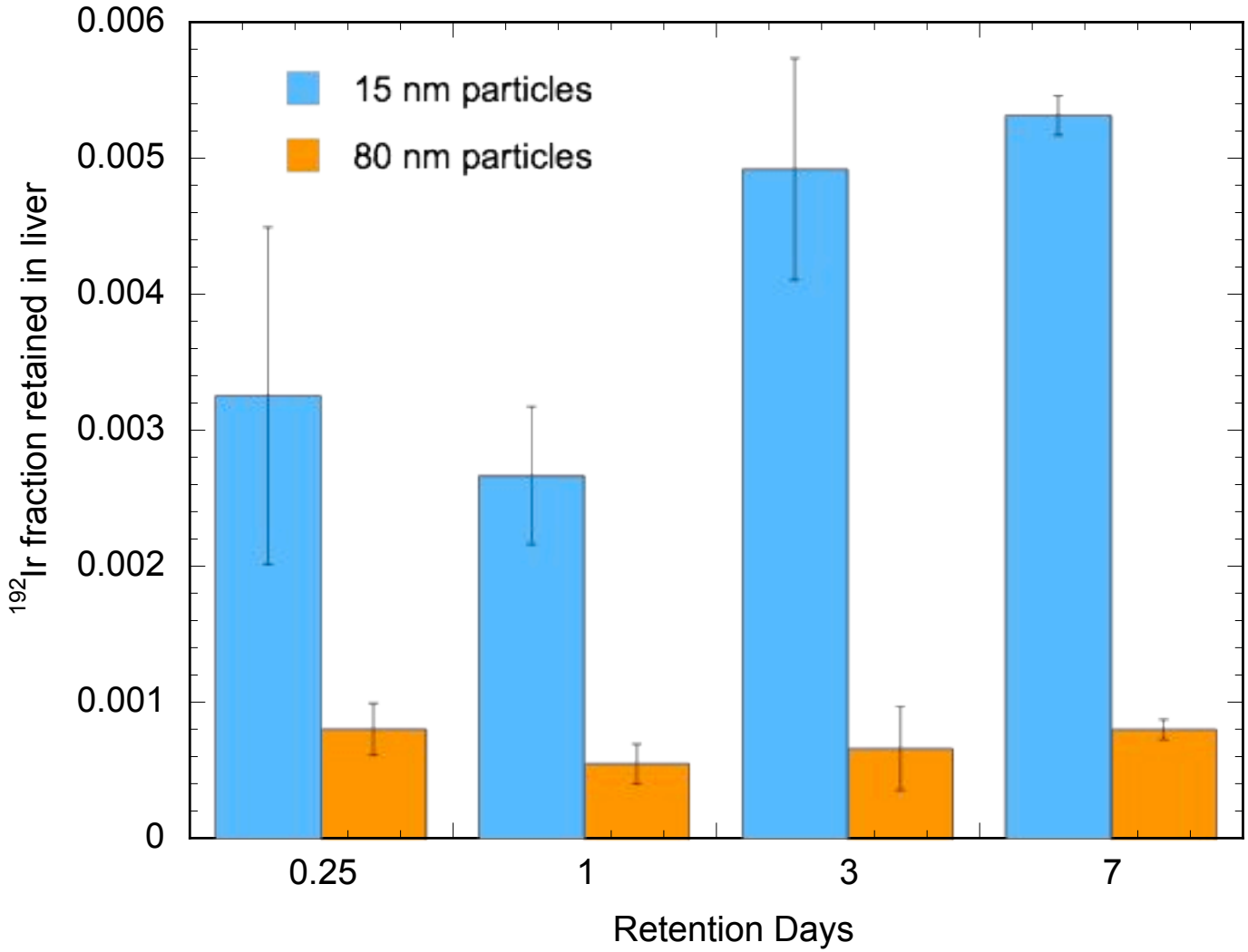


Maynard and Kuempel (2005), Journal of Nanoparticle Research, In Press

Particle Size

Translocation Following Inhalation - Lungs to Liver

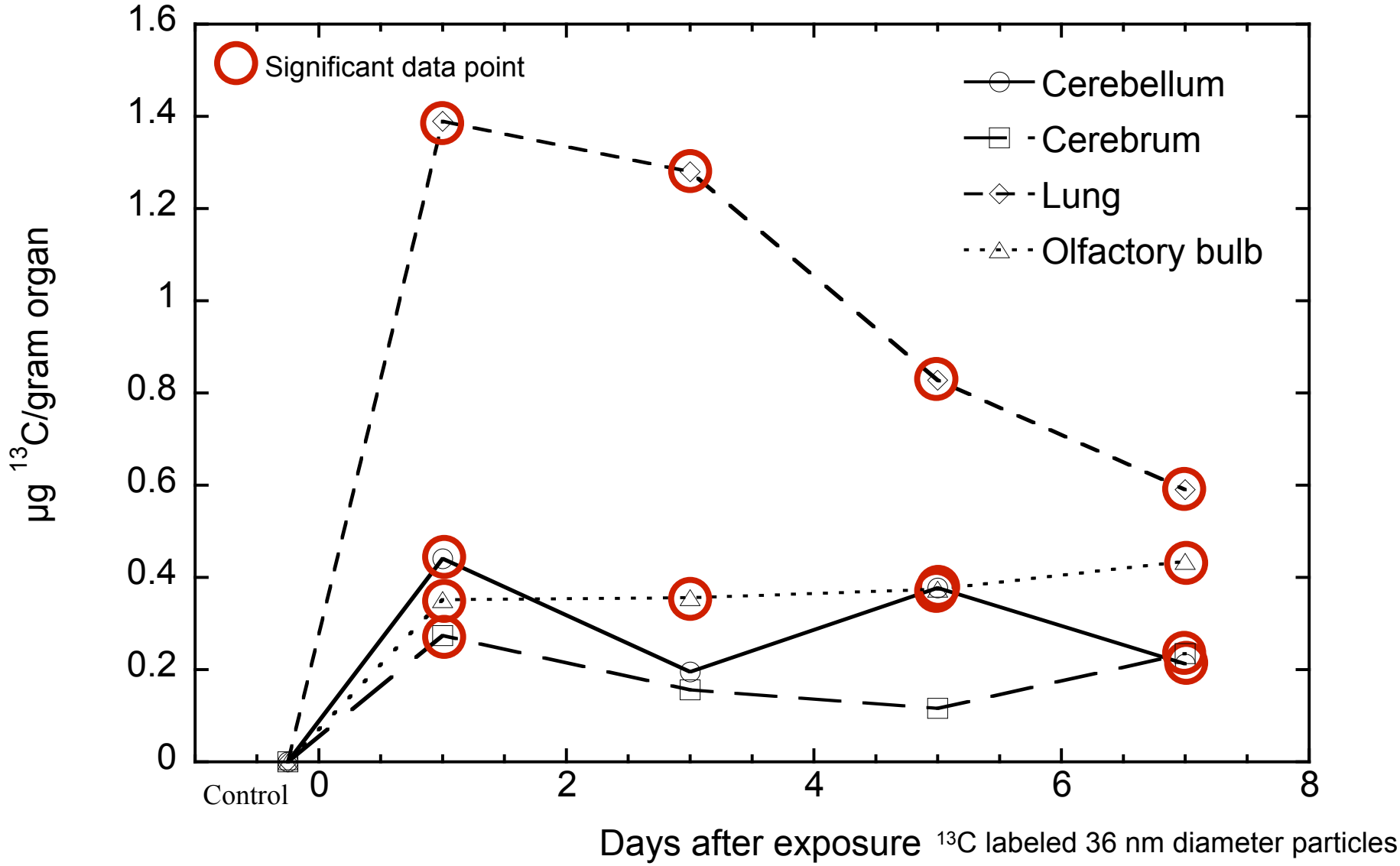
Fraction of inhaled insoluble ^{192}Ir translocating to liver in rats



Kreyling, W. G. et al. (2002). *J. Toxicol. Env. Health Pt A* **65**(20): 1513-1530.

Particle Size

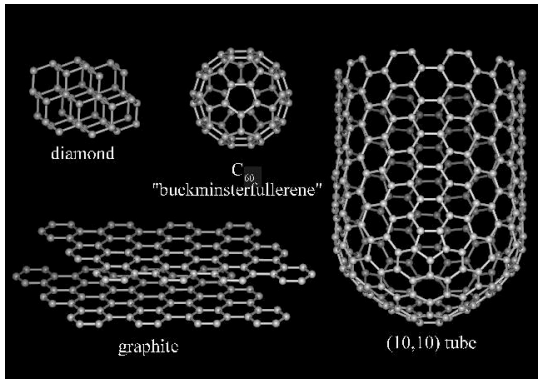
Translocation Following Inhalation - Upper airways to brain



Oberdörster, G., Z. Sharp, V. Atudorei, A. Elder, R. Gelein, W. Kreyling and C. Cox (2004). *Inhal. Toxicol.* **16**(6-7): 437-445.

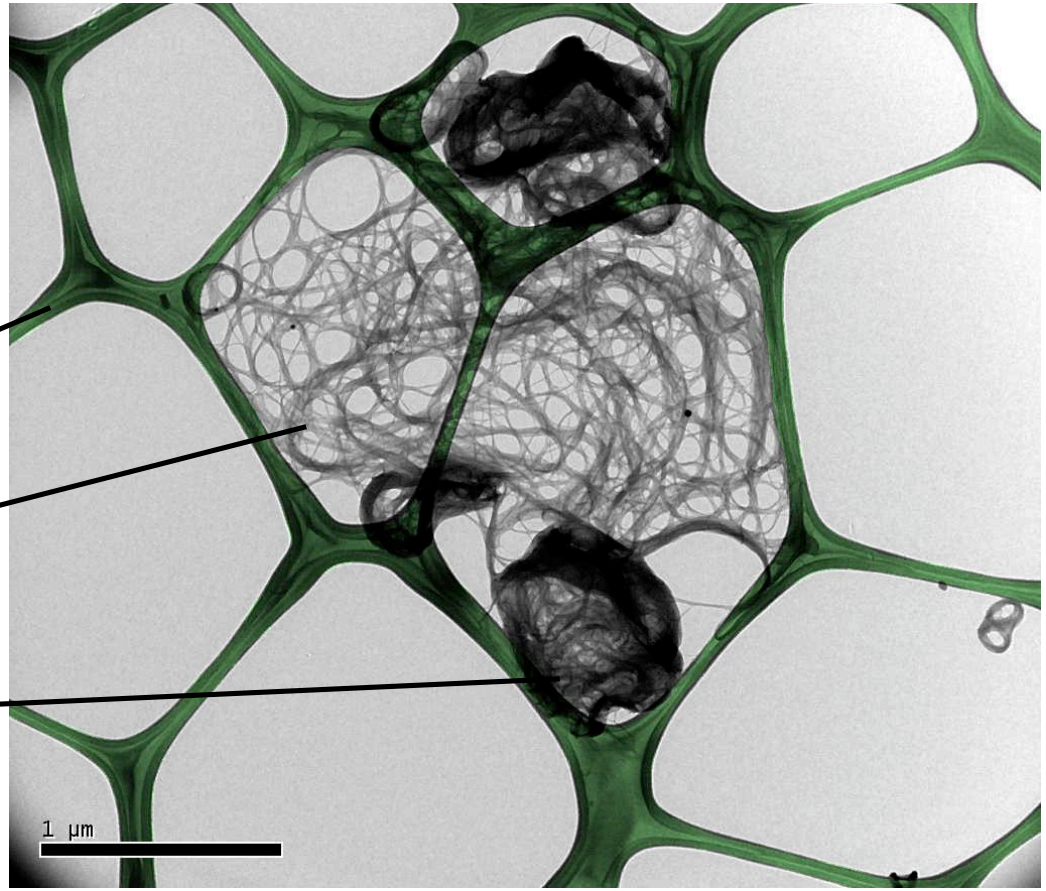
Significance of Morphology

Single Walled Carbon Nanotubes



Allotropes of carbon

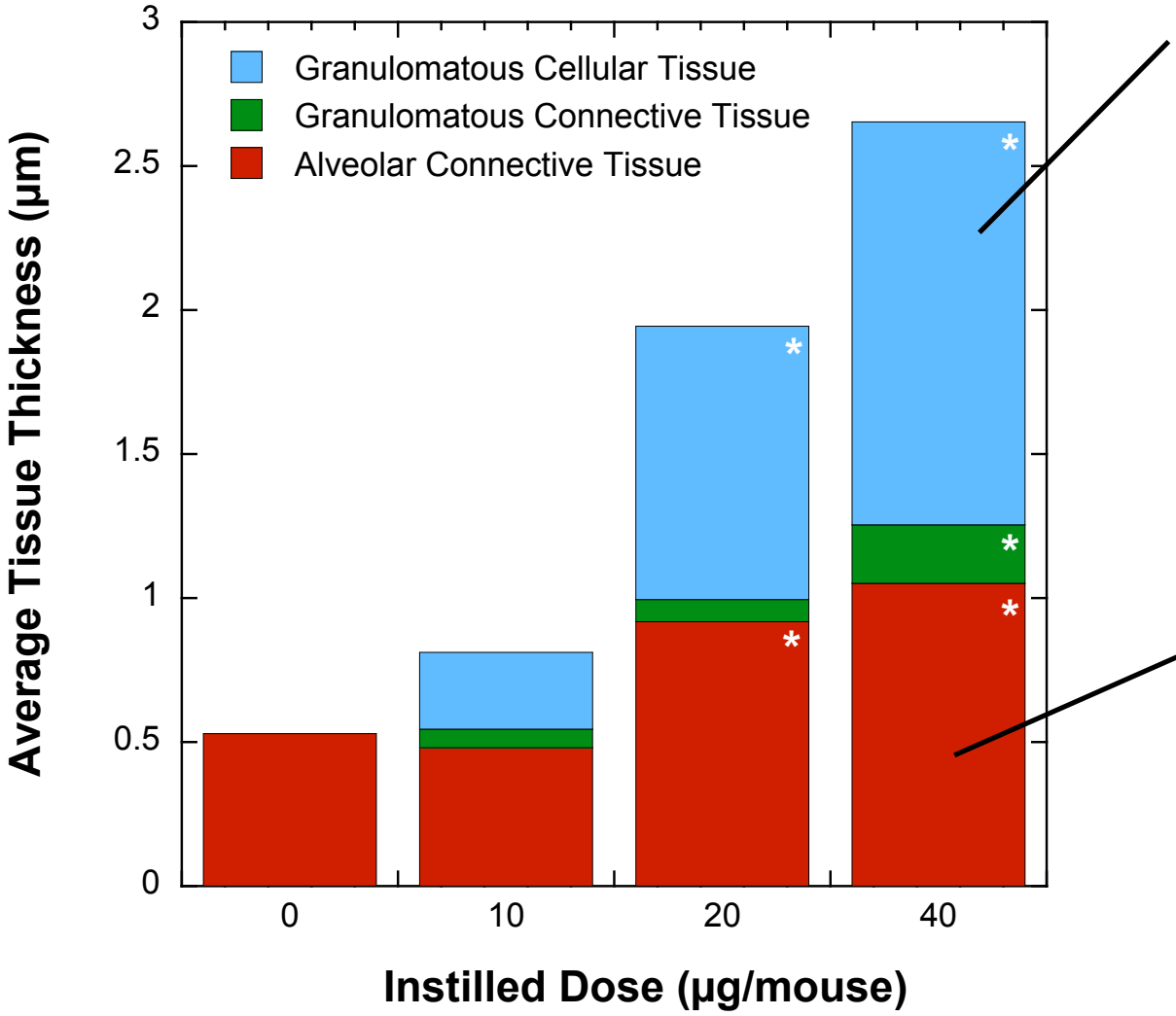
Transmission Electron Microscope image of purified single walled carbon nanotube particles



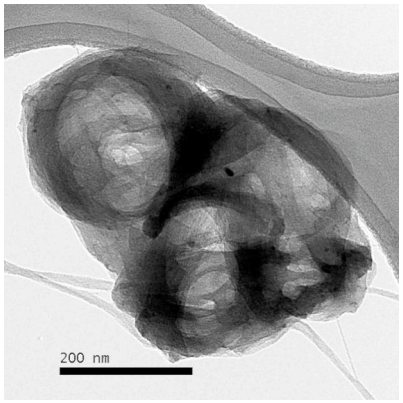
Ku, Evans, Ramsey and Maynard, in Shvedova et al. (2005)

Single Walled Carbon Nanotubes

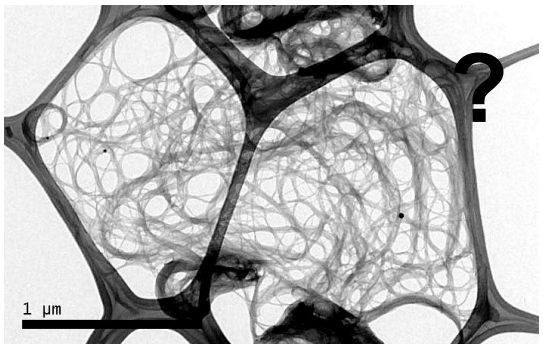
Tissue thickening in mice - Pharyngeal aspiration



Proximal region of lung
Visible SWCNT clumps

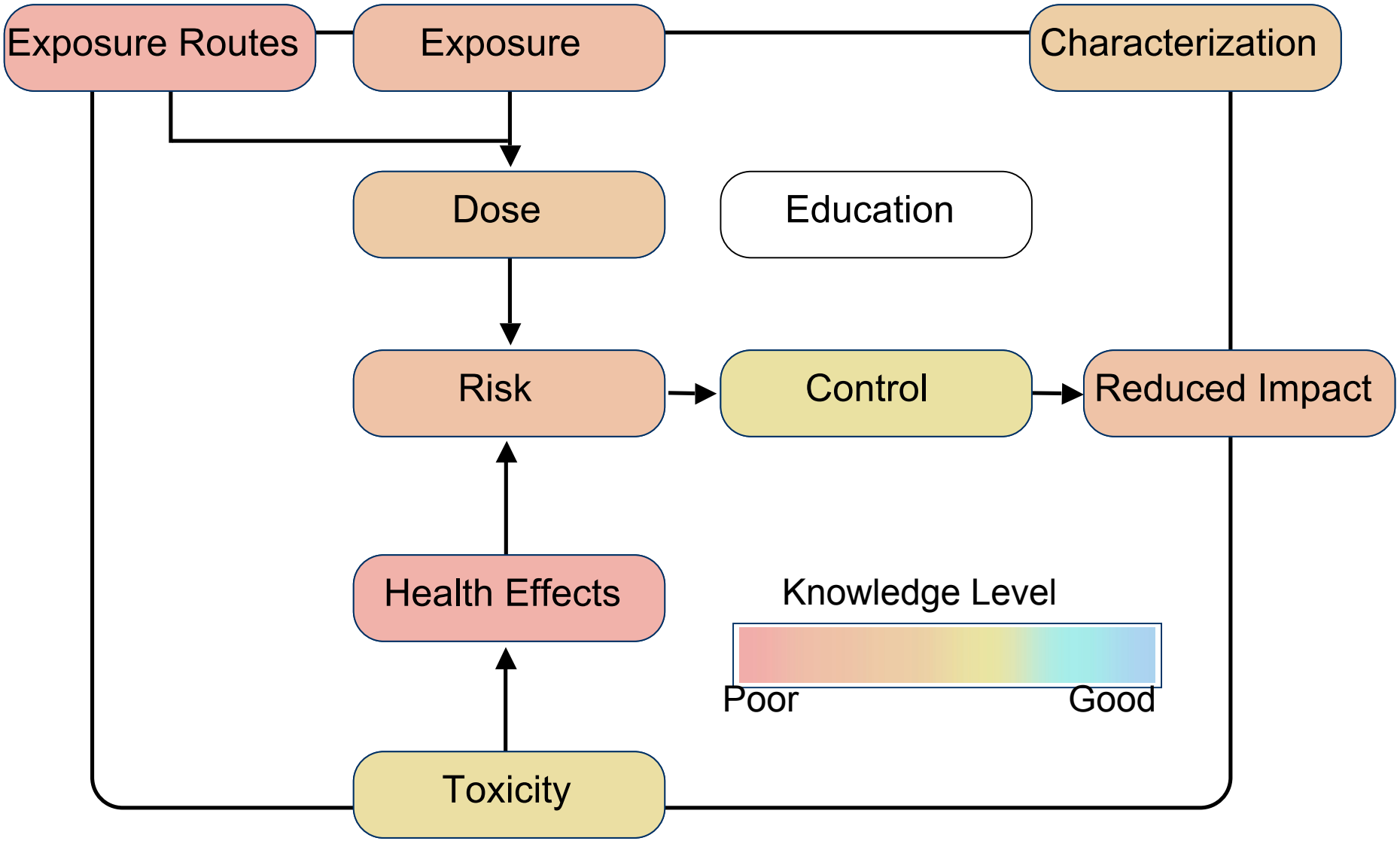


Distal region of lung
No SWCNT visible



Shvedova, et al. (2005) *Am. J. Physiol.-Lung Cell. Mol. Physiol.* 289, 698-708.

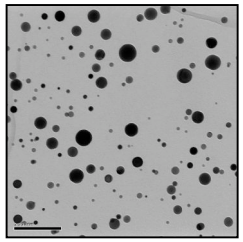
Addressing Occupational Impact



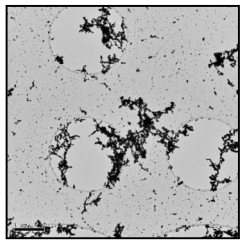
Setting Boundaries

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

Comminution
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

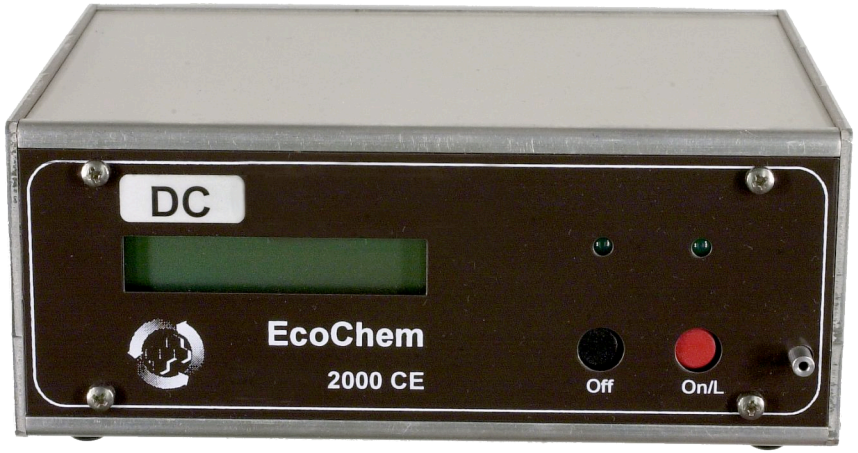
Options

- 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

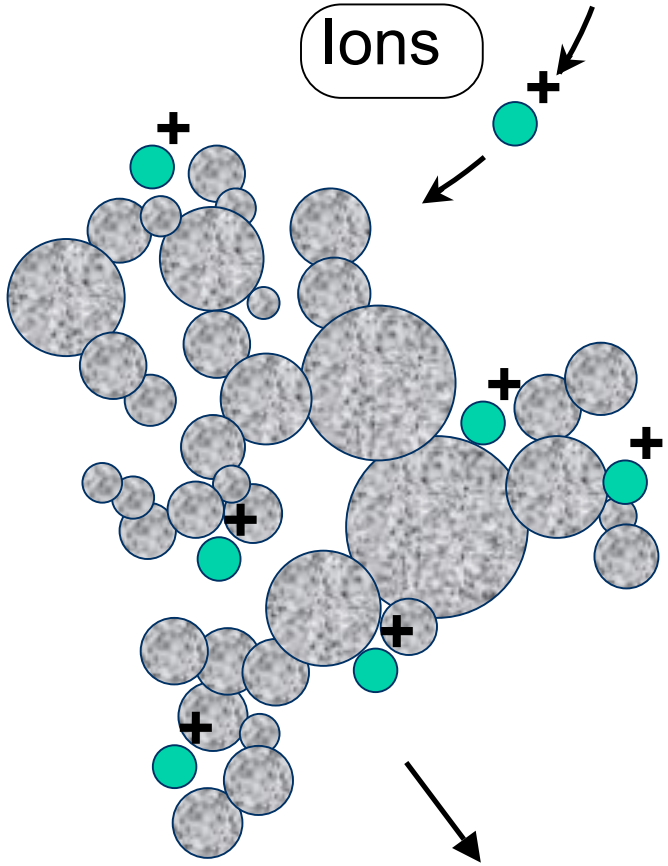
Using attachment rate

Charge on Aerosol $\propto$ **Surface Area**



DC2000 CE Diffusion Charger

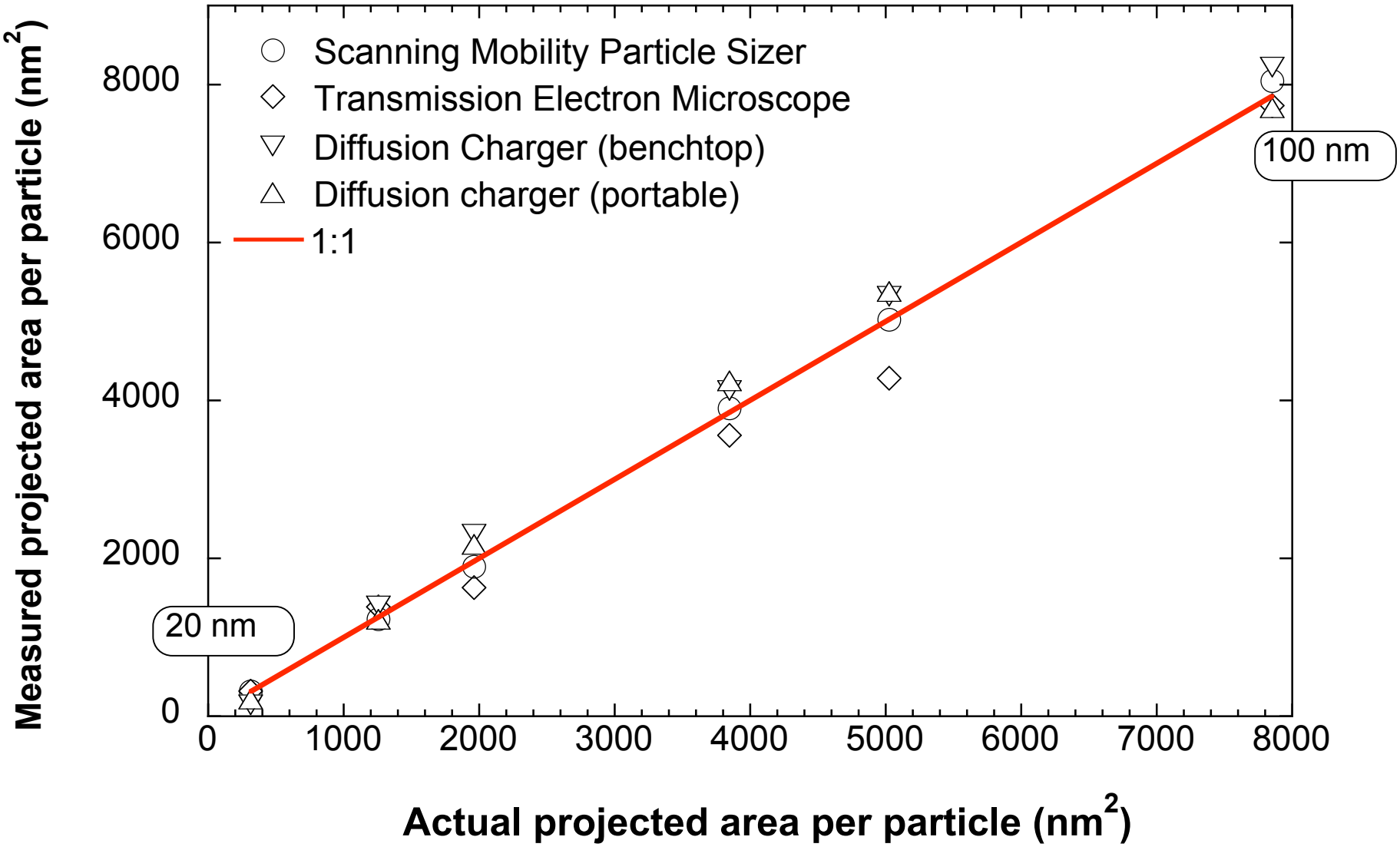
EcoChem



Electrometer

Comparison of Measurement Methods

Monodisperse particles < 100 nm, fractal-like

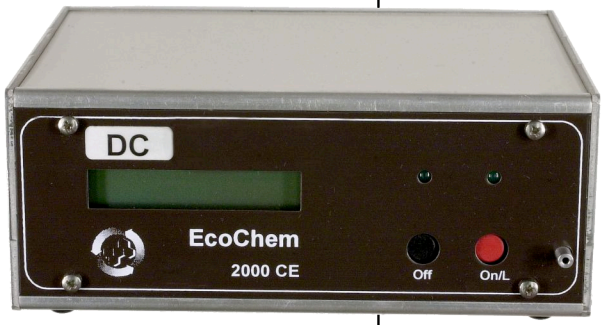


Ku and Maynard, J. Aerosol Sci (in press)

Emerging Measurement Technologies

Deposited Surface Area

Nanoparticle Surface Area Monitor
www.tsi.com



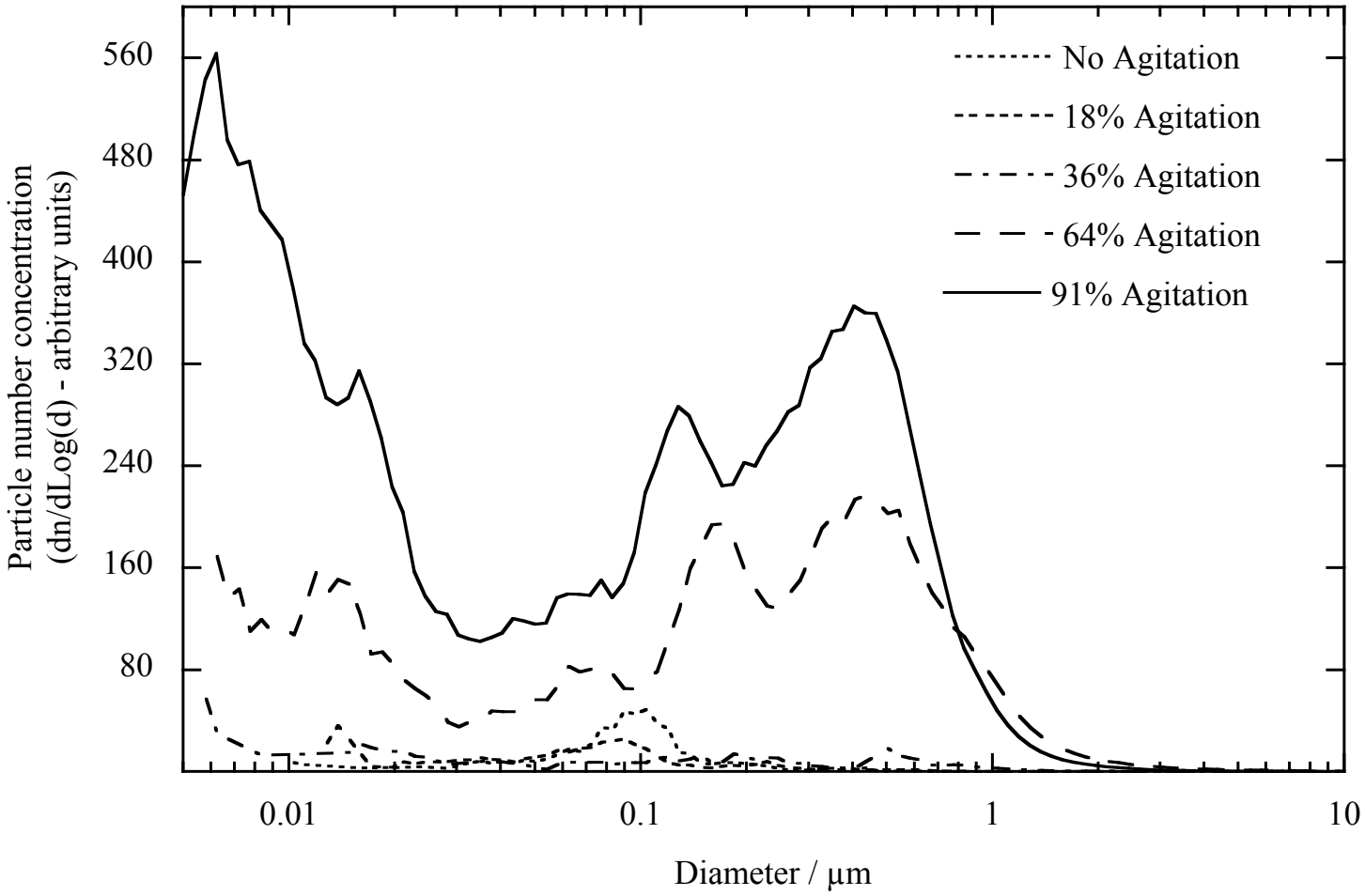
Diffusion Charger
www.ecochem.biz

Wilson et al. (2004)

Handling Nanotube Material

Unprocessed single walled nanotube material

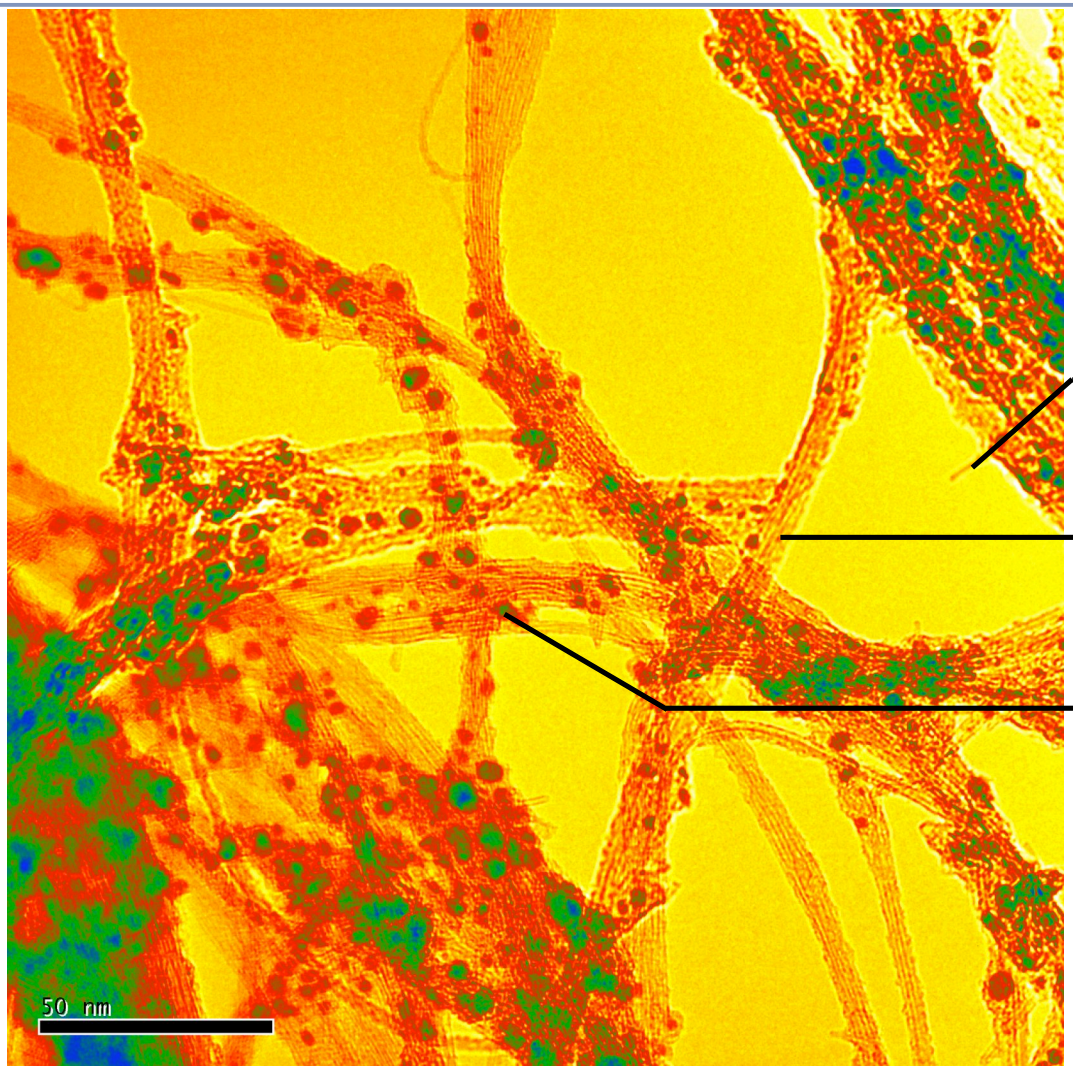
Laboratory Generation of Nanotube Aerosol



Agitation of unprocessed material in an airflow

Maynard, A. D., P. A. Baron, M. Foley, A. A. Shvedova, E. R. Kisin and V. Castranova (2004). *J. Toxicol. Environ. Health* **67**(1): 87-107.

Single Walled Carbon Nanotubes



Nanotubes

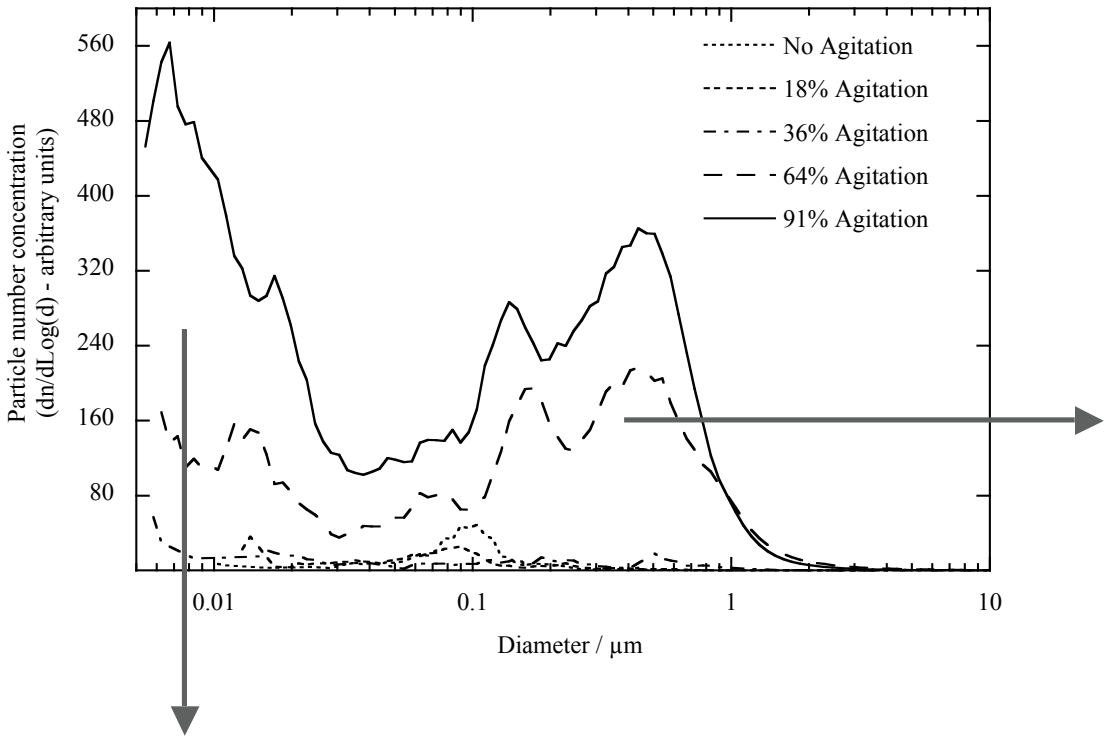
Nanoropes

Catalyst particles

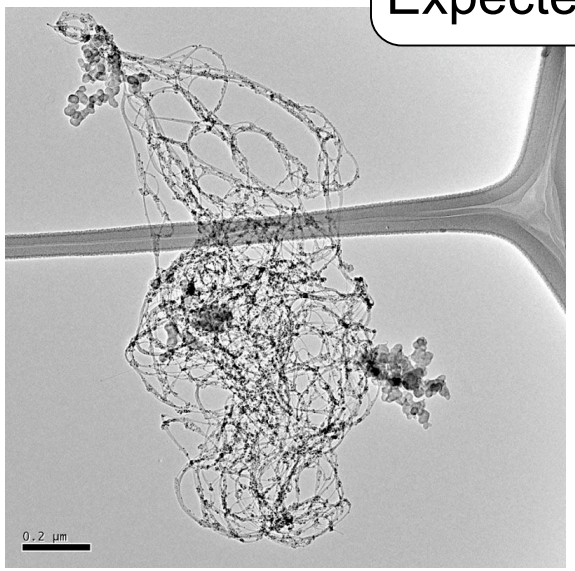
Non-tubular carbon

Raw single walled carbon nanotube material.

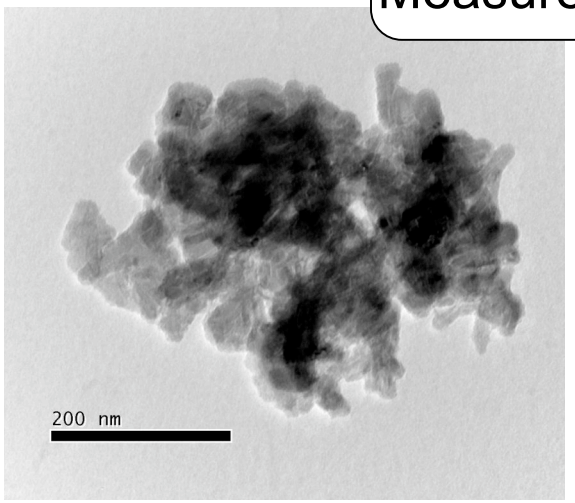
Nanotube Aerosol Characterization



Expected



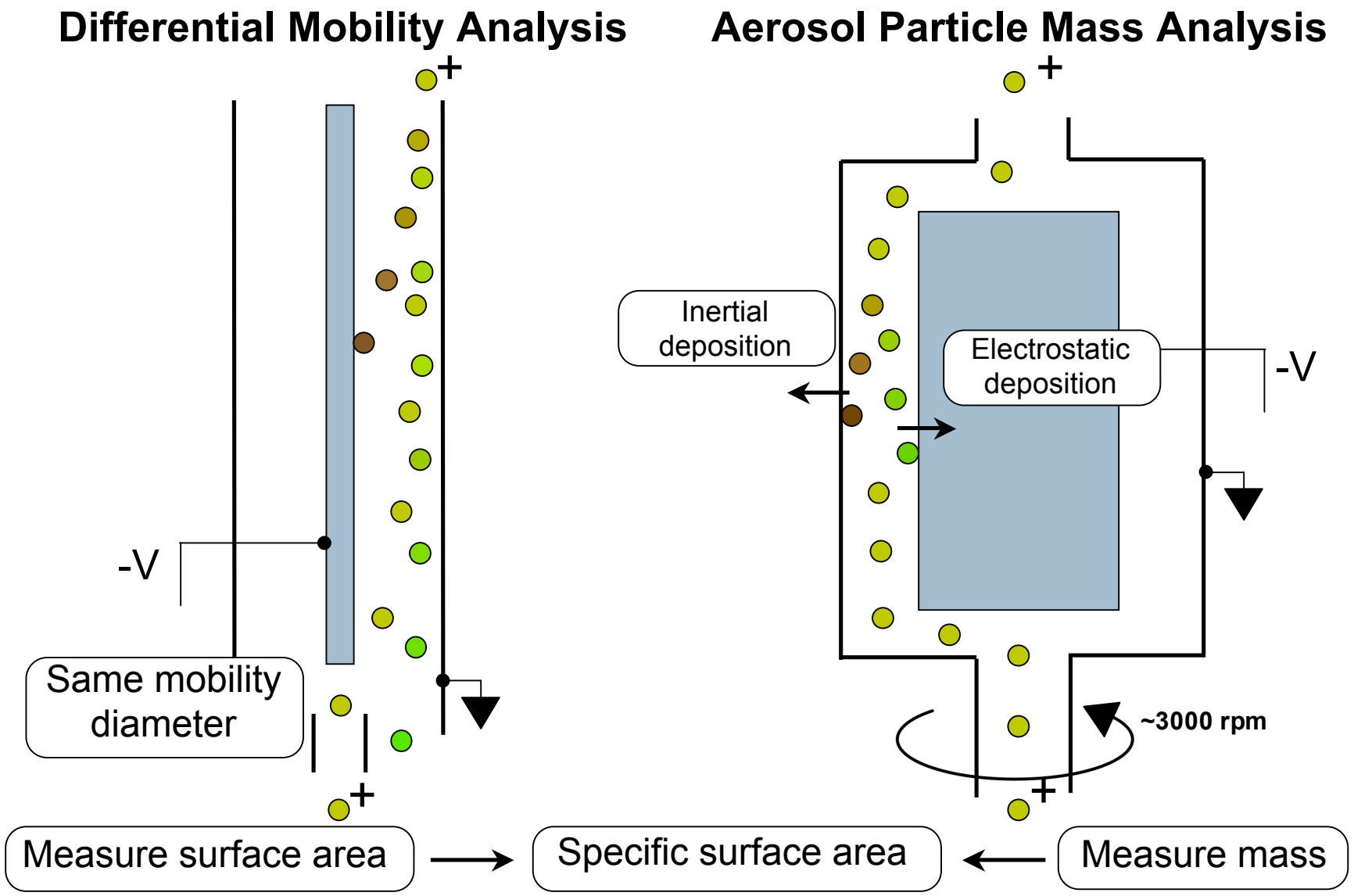
Measured



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

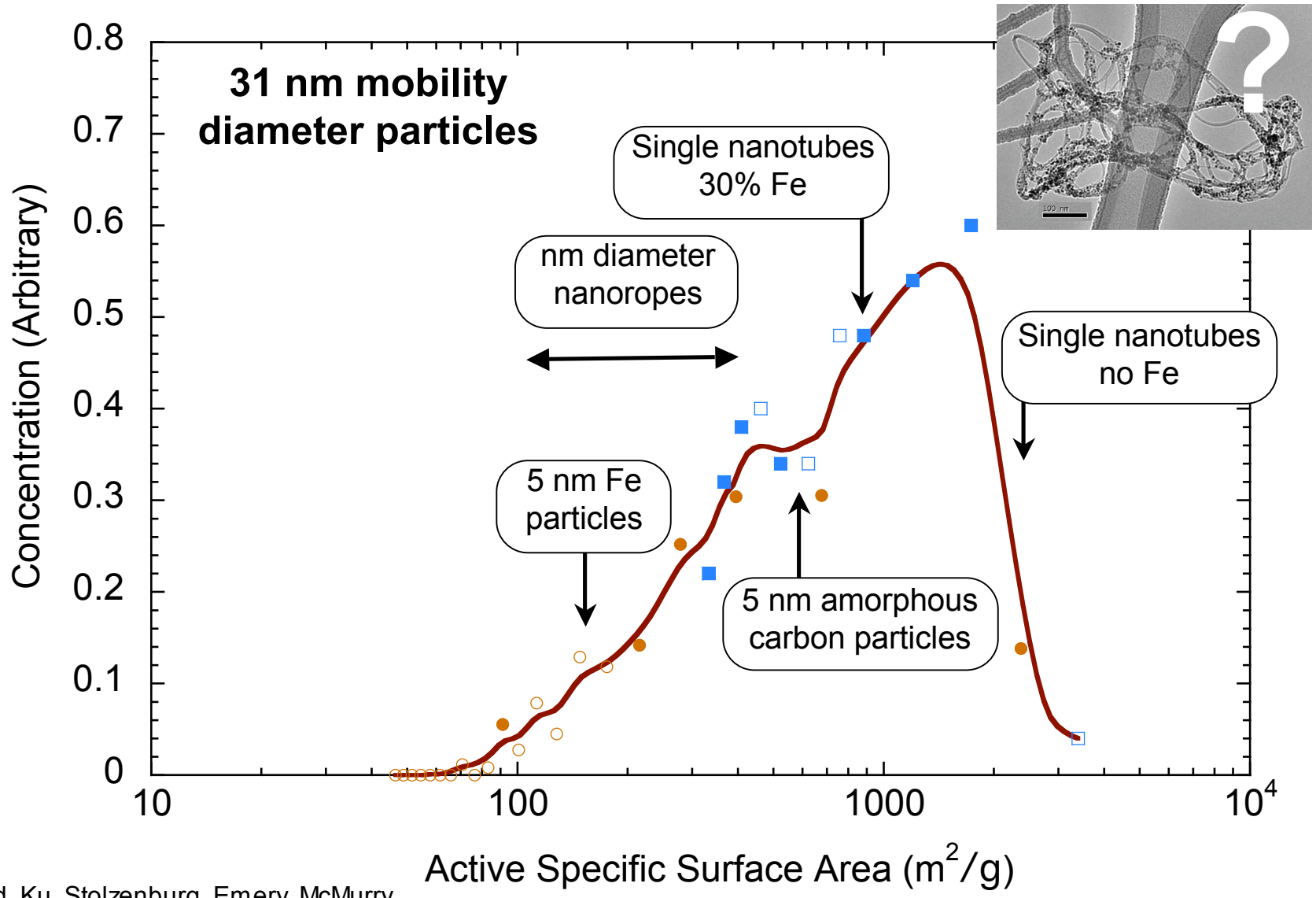
Aerosol Characterization

'Active specific surface area' measurements



Aerosol Characterization

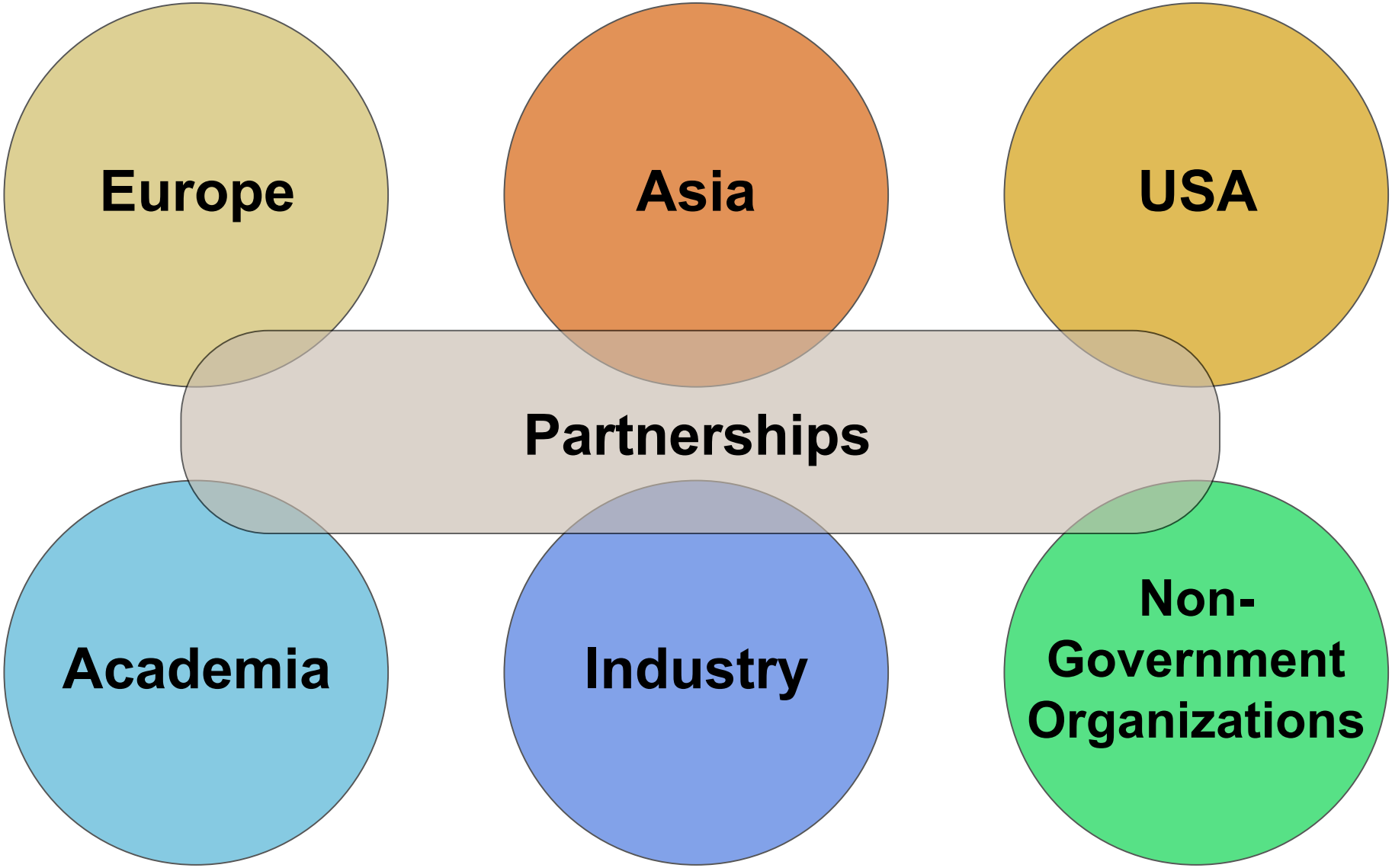
'Active' specific surface area



Maynard, Ku, Stolzenburg, Emery, McMurry

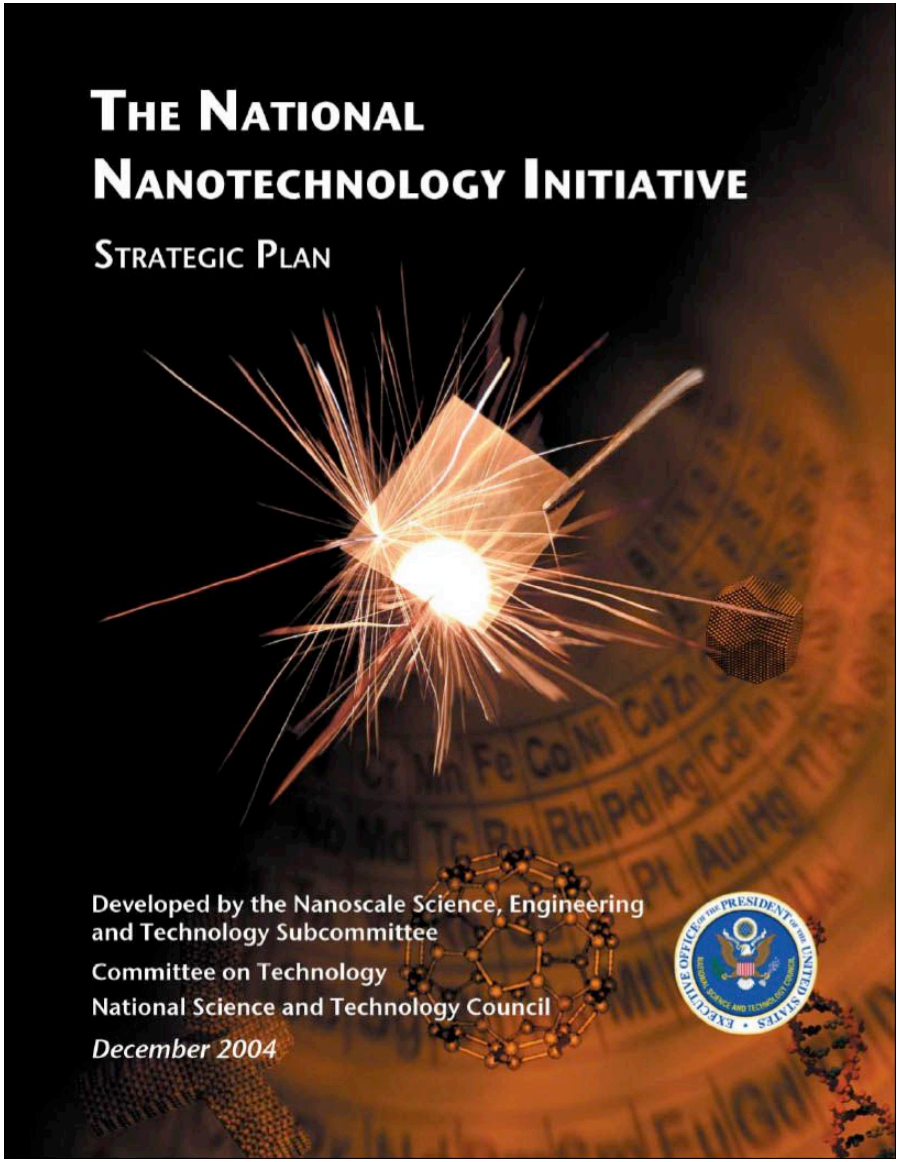
Impact of Engineered Nanomaterials

Global initiatives



National Nanotechnology Initiative

Strategic Plan



- **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

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NIOSH Safety and Health Topic:

Nanotechnology

Strategic Plan for NIOSH Nanotechnology Research: Filling the Knowledge Gaps

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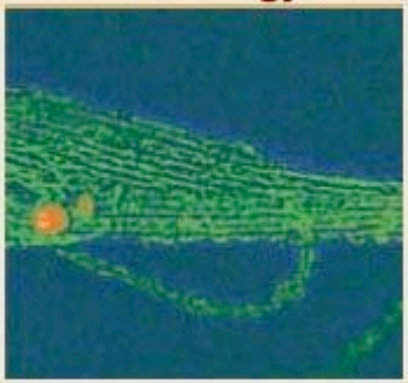
The National Institute for Occupational Safety and Health (NIOSH) is pleased to present the *Strategic Plan for NIOSH Nanotechnology Research: Filling the Knowledge Gaps, September 2005*. The strategic plan provides a guide for building a research effort capable of responding to the challenges of this 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.

Nanotechnology



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Approaches to Safe Nanotechnology: An Information Exchange with NIOSH

www.cdc.gov/niosh/topics/nanotech/strat_plan.html

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Director's Message

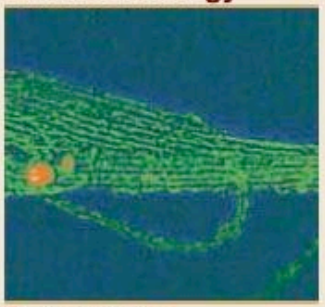
The field of nanotechnology is advancing rapidly and will likely revolutionize the global industry. As with any new technology, we are faced with many unknowns; all of which raise questions concerning occupational safety and health. The National Institute for Occupational Safety and Health (NIOSH) is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

Nanotechnology



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Strategic Plan for NIOSH Nanotechnology Research

Frequently Asked Questions

NIOSH Position Statement

'Focus on Nanotechnology' - Latest Developments at NIOSH

www.cdc.gov/niosh/topics/nanotech/nano_exchange.html

Project on Emerging Nanotechnologies

Woodrow Wilson International Center for Scholars

- Goal

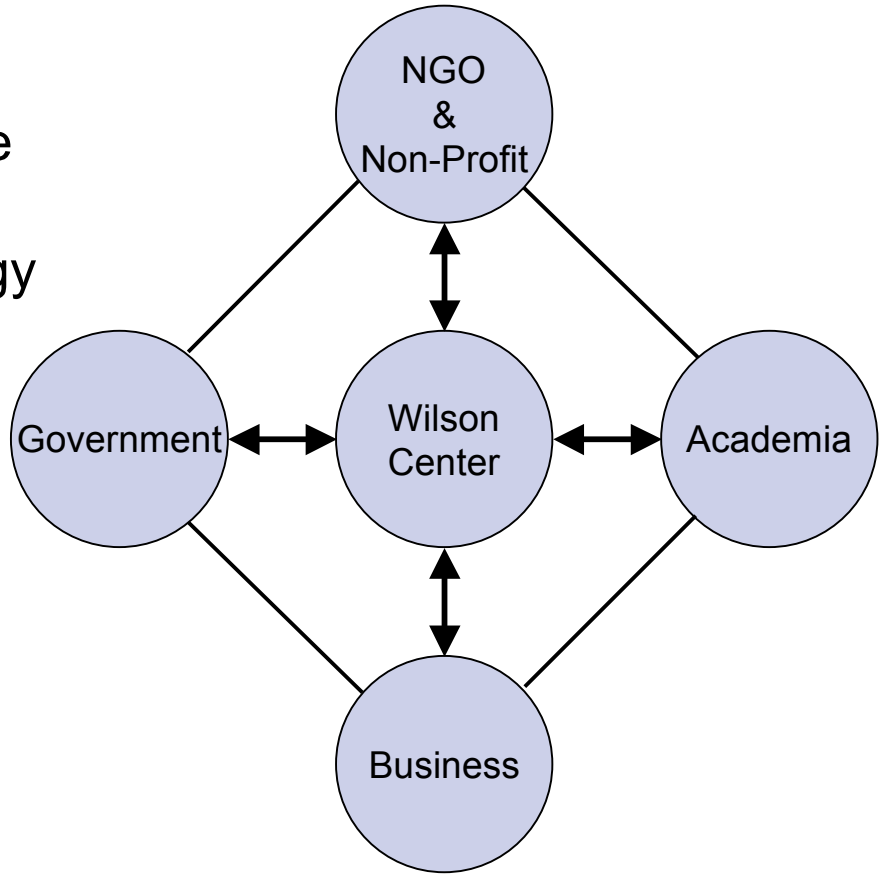
  Ensure government and private sector address the risks as well as the benefits of nanotechnology

- 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

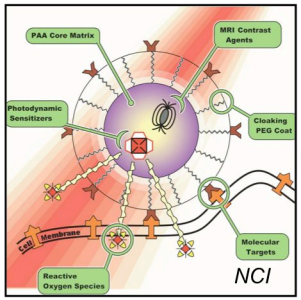
Moving beyond the health impact of 'simple' nanomaterials

Photo by Maximilian Franz, courtesy of Reactive nanotechnologies Inc.

Safety

"Unconventional" and unanticipated behavior

Kopelman & Philbert, UMich



Complex nanoparticles and nano-devices

Moving beyond simple response mechanisms

♥Institute for Molecular Manufacturing
www.imm.org

Convergence

Revolutionary Health & Safety Challenges

www.liftport.com

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