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# Nanotechnology

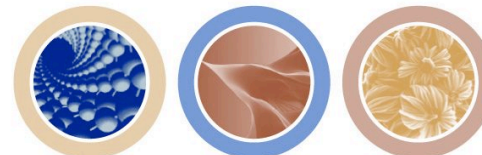
## Overview and Relevance to Occupational Health

**Andrew D. Maynard**  
Chief Science Advisor

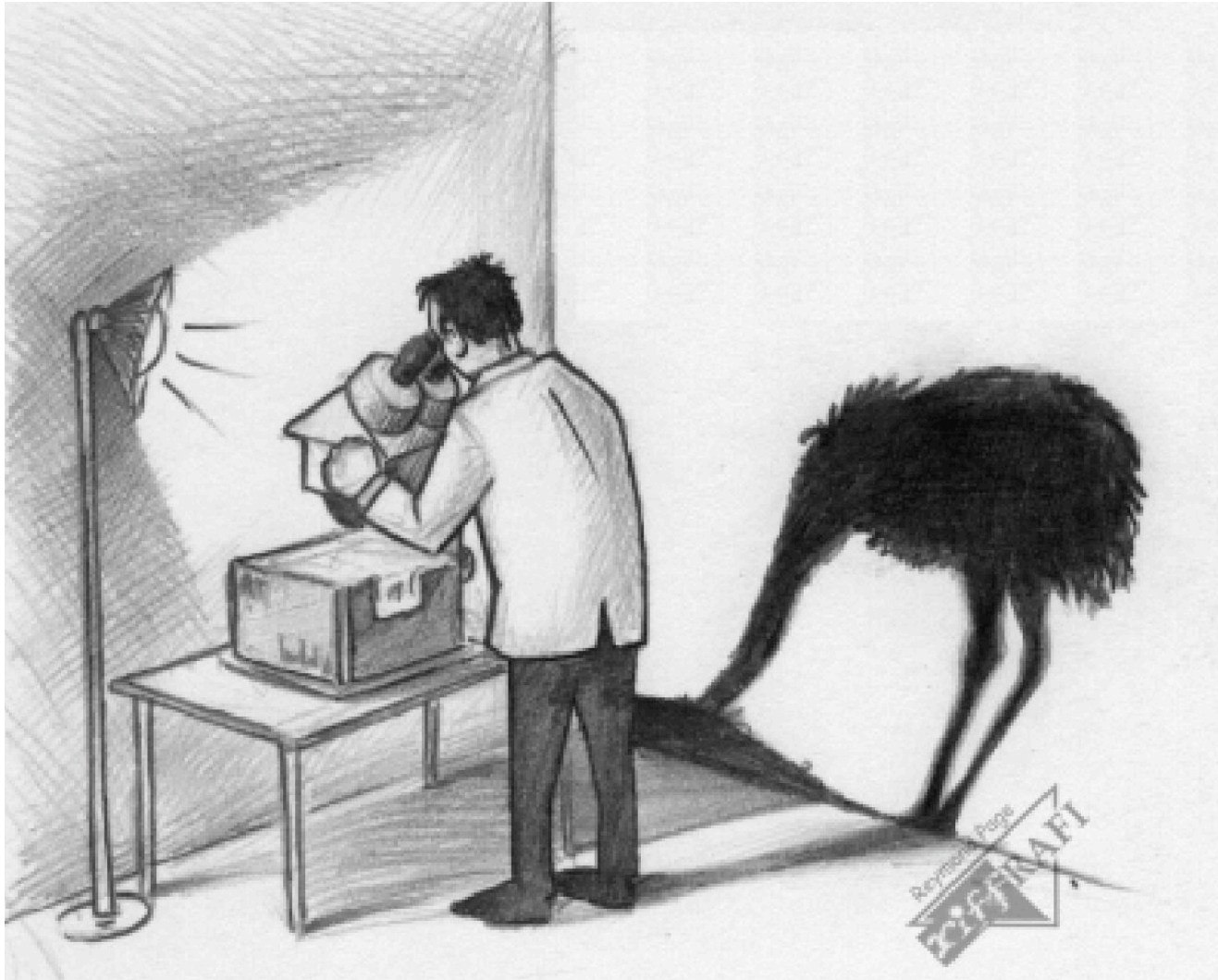
Project on  
**Emerging Nanotechnologies**  
at the Woodrow Wilson International Center for Scholars



**THE PEW CHARITABLE TRUSTS**



# Nanotechnology and Potential Health Impact



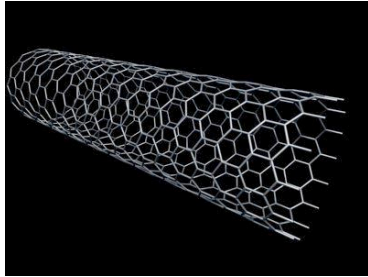
ETC Group Occasional paper Series. Volume 7 No. 1. April 2003



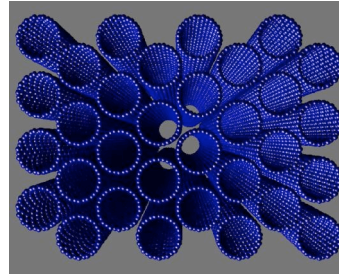
# Nanotechnology

## Science Fiction or Science Fact?

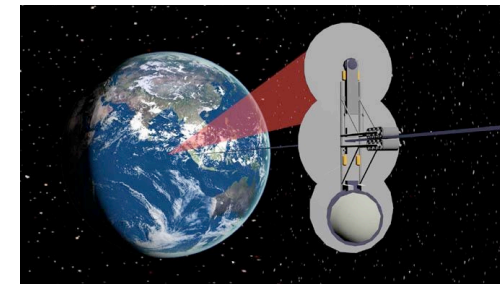
Imagine...



A material where strength is governed by atomic bonds...



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



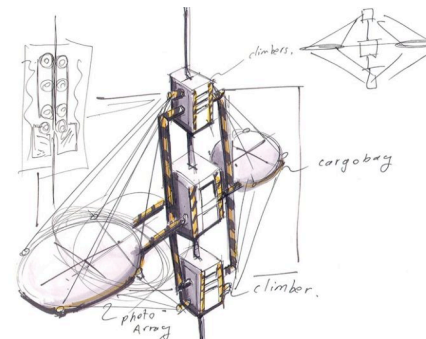
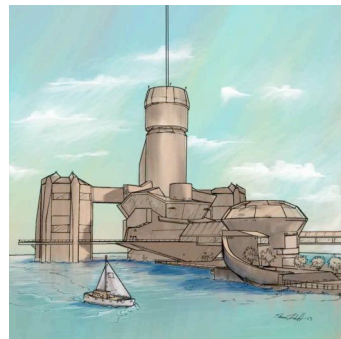
... and used to build an elevator to space!

Nanotechnology is turning fiction to reality...



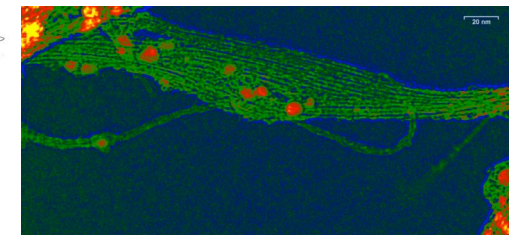
[www.liftport.com](http://www.liftport.com)

**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

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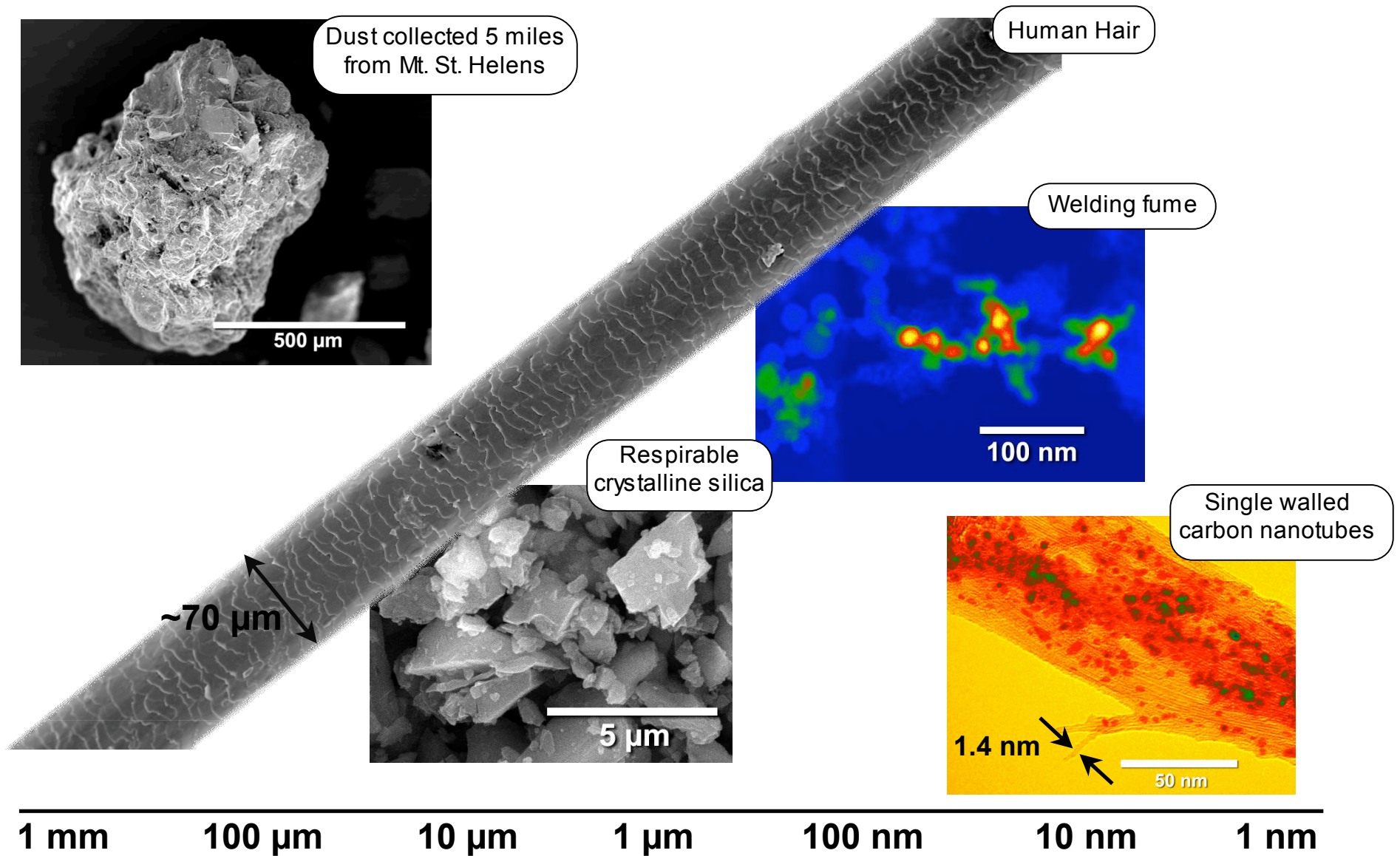
- Definition
  - Development/engineering of new devices and materials which demonstrate unique properties associated with structures on a nanometer length-scale
  - Nanometer scale: less than ~100 nm
  -
- Includes:
  - Engineered nano-scale surface layers
  - Engineered nano-scale structures (discrete or heterogeneous)
  - Engineered nano-scale devices





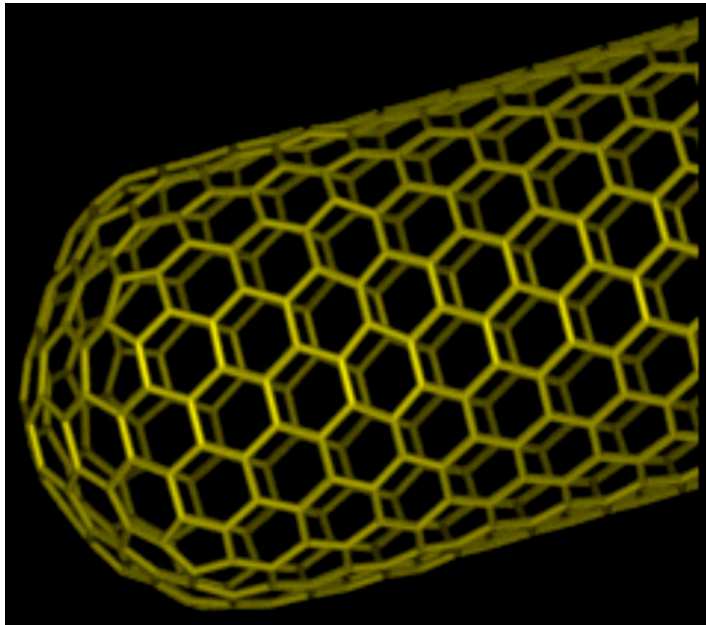
# From Micro to Nano..

“Nano” is less than 100 nm

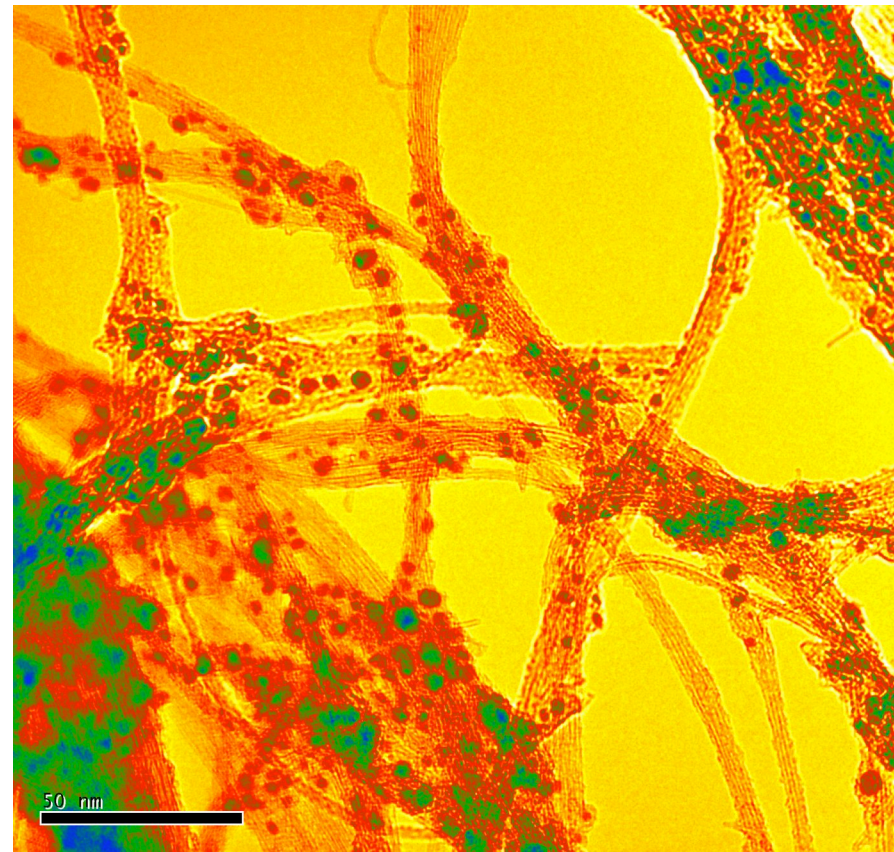


# Unique Structures and Morphologies

## Single Walled Carbon Nanotubes



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



Transmission Electron Microscopy

# Unique Quantum Properties

Quantum Dots - particle size determines fluorescence



©Felice Frankel. [web.mit.edu/felicef](http://web.mit.edu/felicef). This image is part of the larger “Envisioning Science Project” at MIT

Smaller  
particles



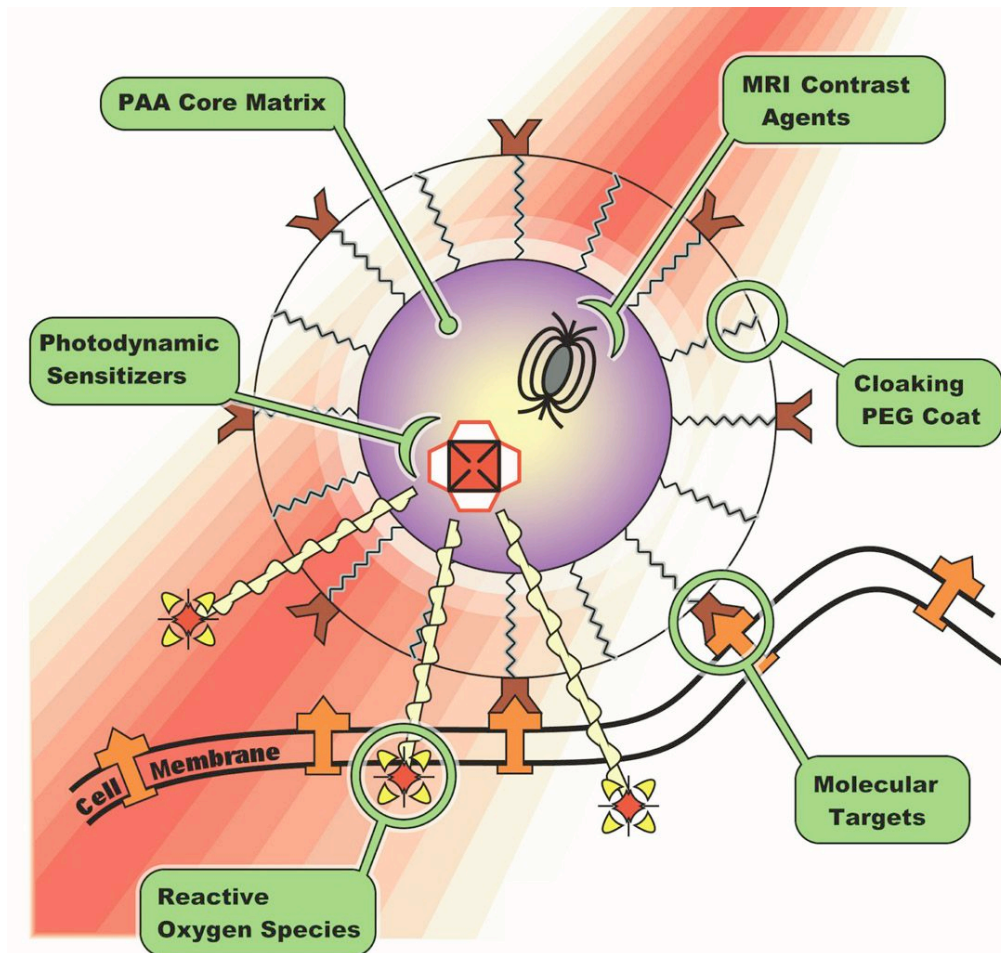
Larger  
particles





# Unique Devices

'Smart' multifunctional nanoparticles



Raoul Kopelman and Martin Philbert, University of Michigan

**cancer NANOTECHNOLOGY**

**Going Small for Big Advances**  
Using Nanotechnology to Advance  
Cancer Diagnosis, Prevention  
and Treatment

U.S. DEPARTMENT OF  
HEALTH AND HUMAN SERVICES  
National Institutes of Health  
National Cancer Institute

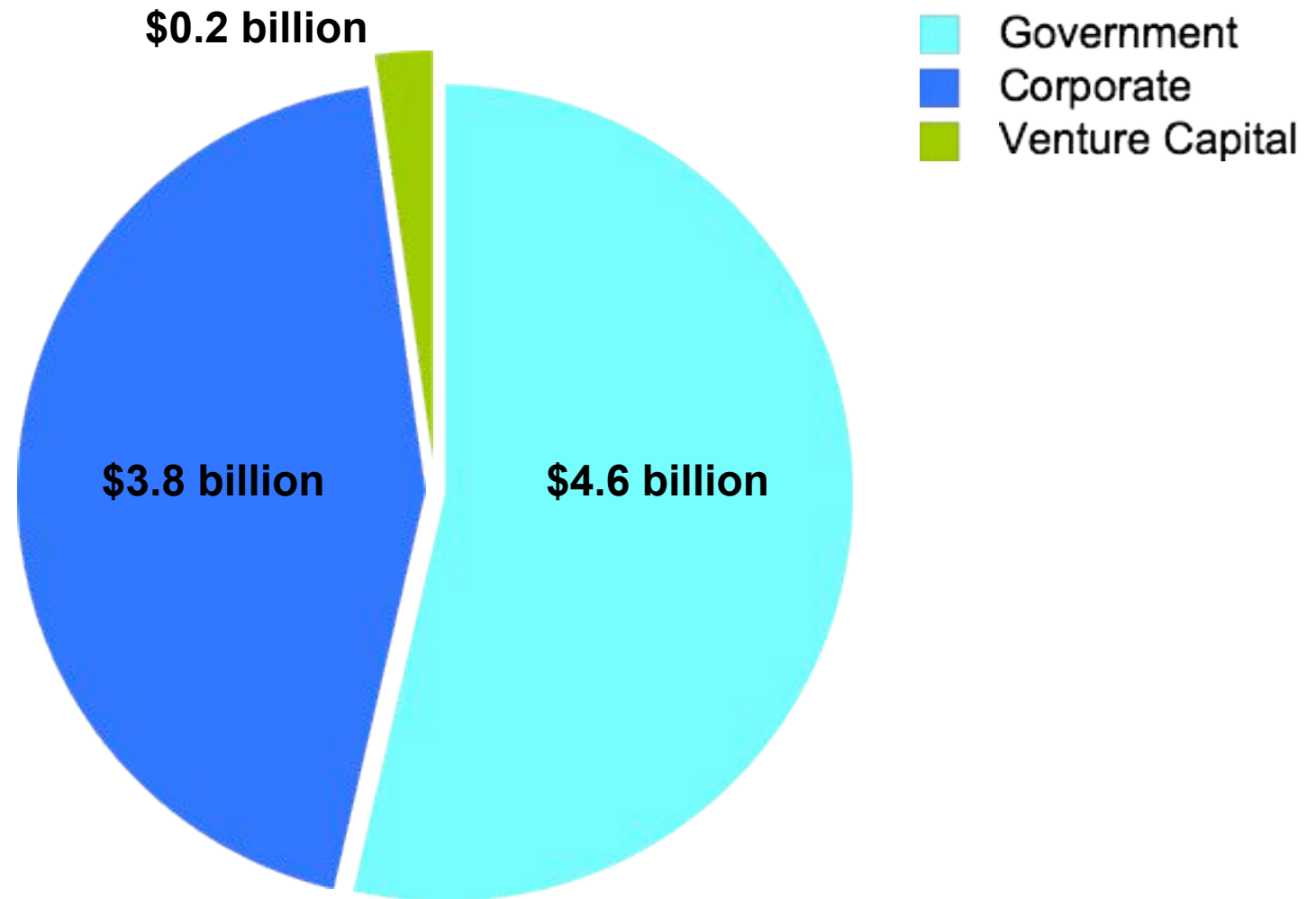
[nano.cancer.gov](http://nano.cancer.gov)



# Nanotechnology Investment and Impact

## Global R&D Investment in 2004

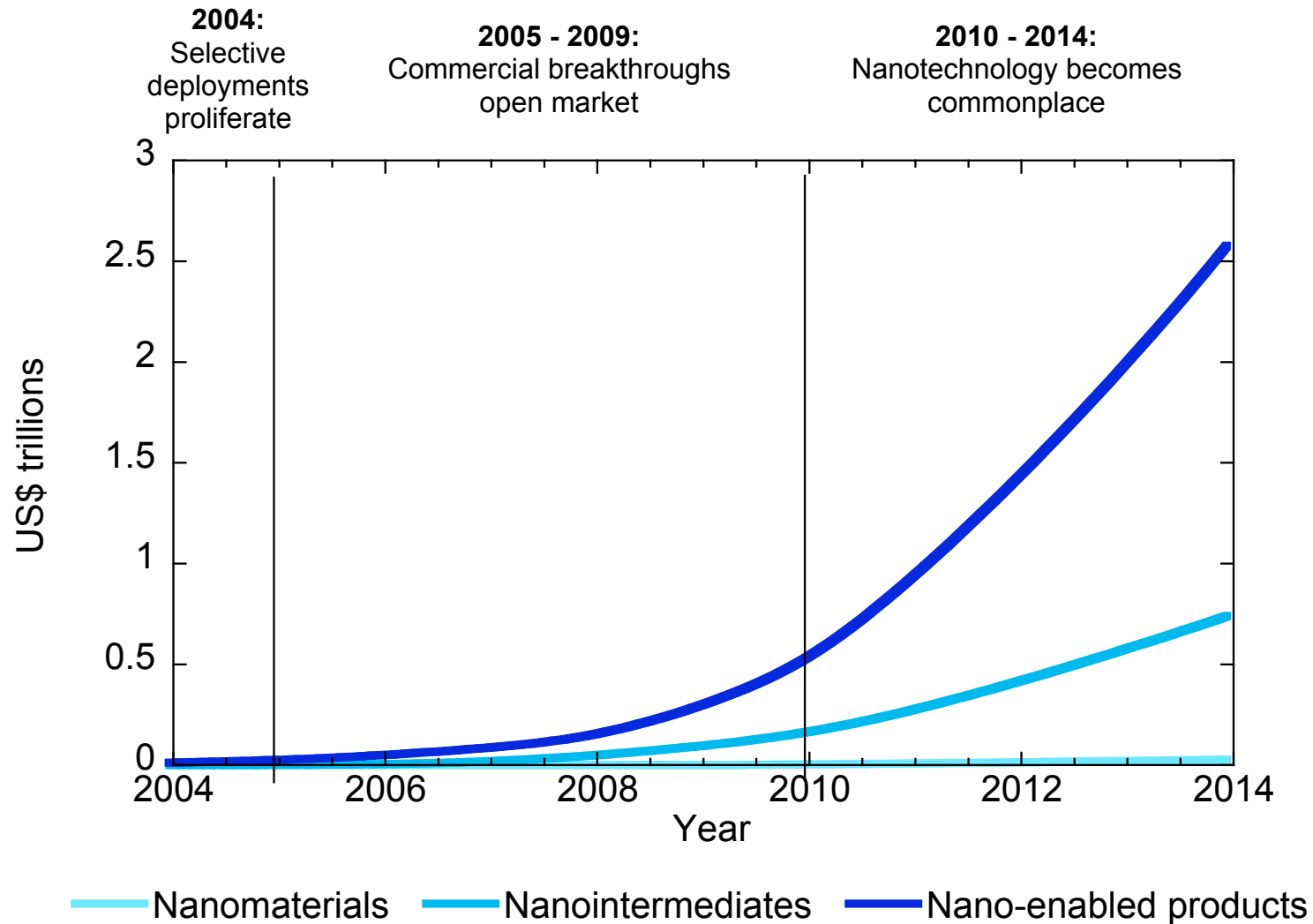
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Source: 2004 Lux Research Reference Study: "The Nanotechnology Report 2004"

# 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.eastonbike.com

## Easton CNT is Real Nanotechnology

**The Bucky Ball**  
Discovered in the eighties, the Bucky Ball derives its name from noted architect Buckminster Fuller. Sixty carbon atoms, each sharing covalent bonds with three other carbon atoms, is similar to the structure of the carbon nanotube.

**The Carbon Nanotube (CNT)**  
A carbon nanotube is a structure one billionth of a meter

**Easton's Tiny Innovation is Huge**  
Easton has an eighty-three year history of leading the market by developing new materials and innovative products. Easton has been manufacturing sporting goods using carbon-fiber composites since 1989 and has been the leading brand of composite bicycle handlebars since their introduction in 1991.

Now Easton's research and development team is proud to announce a major breakthrough in composite materials and manufacturing.

**The Next Frontier**  
Nanotechnology is the next frontier in scientific research and manufacturing. Nanotechnology deals with the manipulation of matter on the atomic or molecular scale measured in billionths of a meter (nanometers). Scientists worldwide are spending countless man-hours and billions of dollars on research and development for uses for nanotechnology in the areas of electronics, medicine, and structural reinforcement.

**Enhanced Resin System™**

### Carbon Nanotube Composite

NANotex™ Fabric

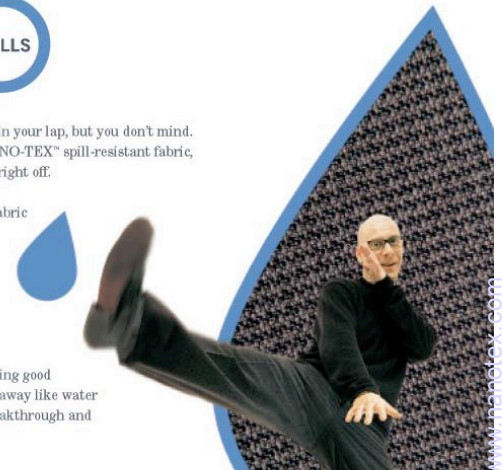
resists



...ed an iced latte in your lap, but you don't mind. ...s made with NANO-TEX™ spill-resistant fabric, ...ads up and rolls right off.

...e conventional fabric ...l seen before. ...o-TEX builds ...the very fibers ...is keeps the ...soft, and ...they should be.

...fabric, you're looking good ...mplications roll away like water ...perience the breakthrough and ...er's next.



### Nano fibers

www.wilson.com

www.3M.com

## Filtek™ Supreme Universal Restorative

Say goodbye to microfills and hybrids with our revolutionary new nanocomposite based restorative.

**It's good to be king!**

**3M ESPE**

### Nanosilica Composite



# Defining the Issue

## Nanotechnology and Occupational Health

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- **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**

**etC group**  
Volume 7, No. 1  
**No Small Matter II: The Case**



Industry and government regulators maintain that nanoscale materials do not warrant a closer look at environmental impacts. In this *Occasional Paper*, matters!

ETC Group, P.O. Box 68016 RPO Osborne  
Tel: 204 453-5259 Fax: 204 284

**VDI (Germany) 2004**

**VDI Technologiezentrum**

Technologien  
Industrial application of nanomaterials – chances and risks

With the support of the European Union



**Swiss Re 2004**

**Swiss Re**

Nanotechnology  
Small matter, many unknowns

Risk perception

**Royal Society 2004**

**Nanotechnology Looking As We Leap**

Environews . Focus

THE ROYAL SOCIETY

ROYAL ACADEMY OF ENGINEERING

Nanoscience and nanotechnologies: opportunities and uncertainties  
Summary and recommendations



RS Policy document 20/04  
RAEng Policy document R2.19  
July 2004  
ISBN 0 85403 605 9

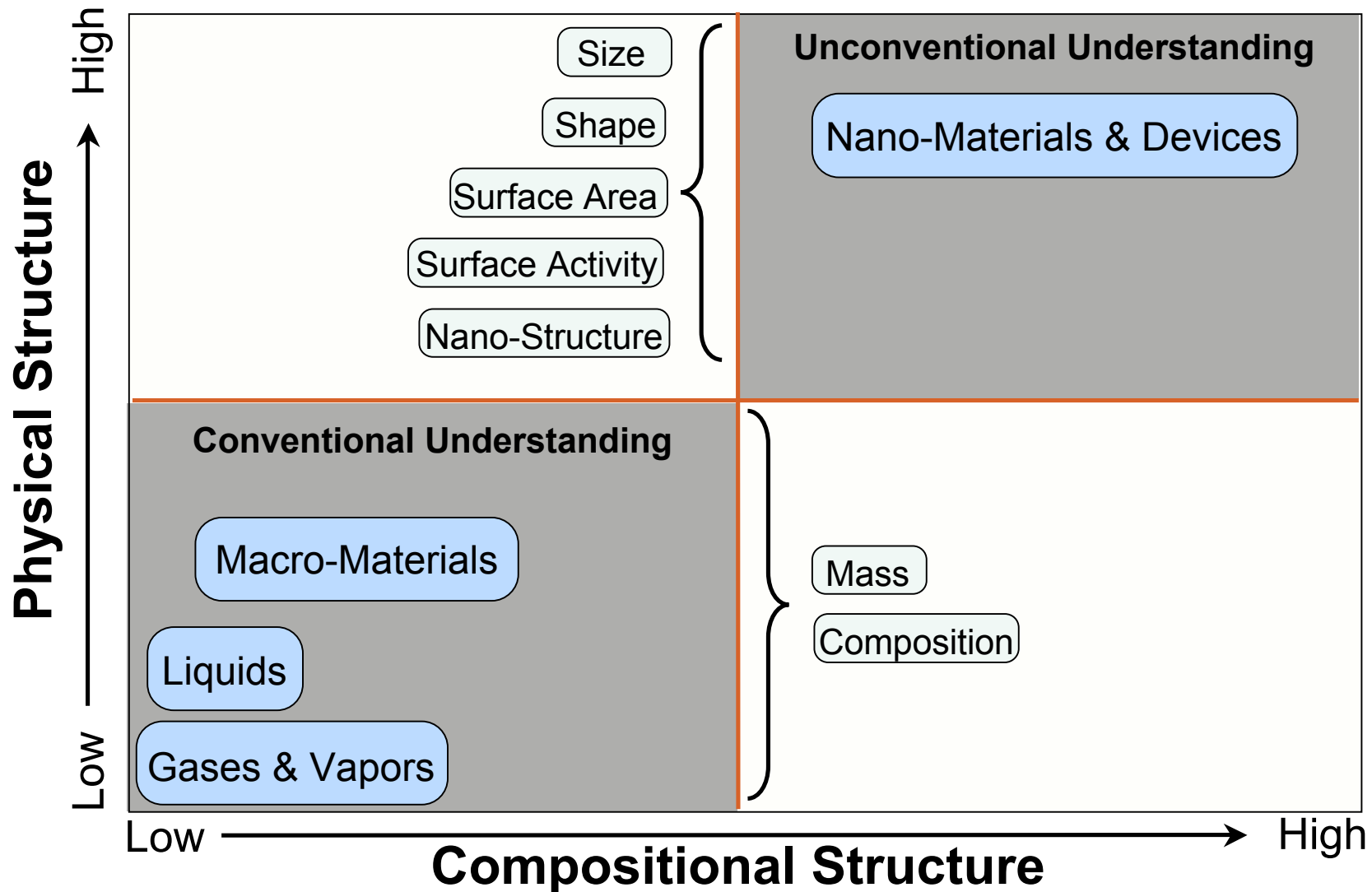
This report can be found at [www.royalsoc.ac.uk](http://www.royalsoc.ac.uk) and at [www.raeng.org.uk](http://www.raeng.org.uk)



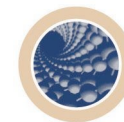
# Potential Health Impact

What makes 'nano' different?

## Influence of structure on potential health impact

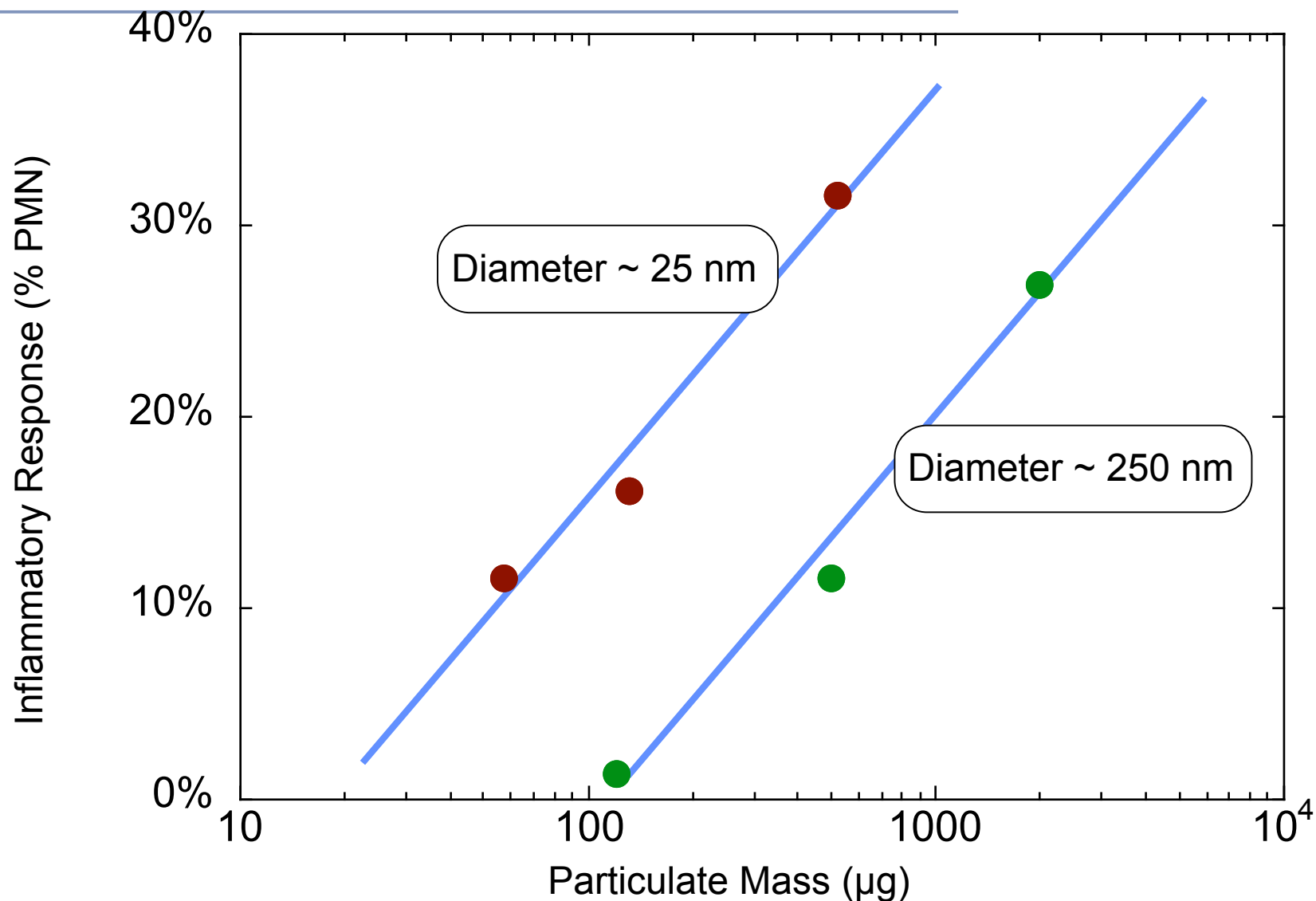






# TiO<sub>2</sub> Instillation in Rats

Oberdörster et al. (2000)

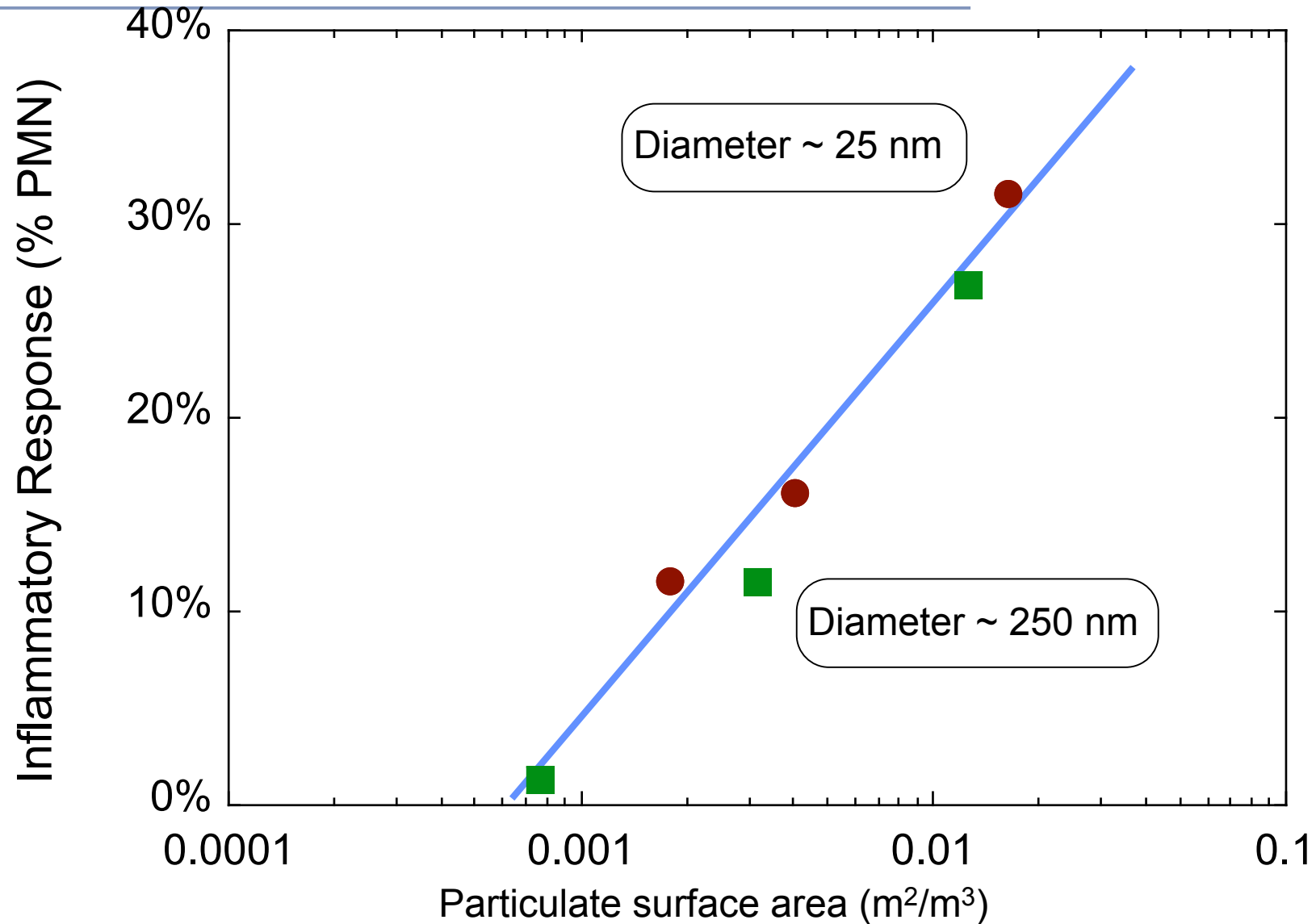


Oberdörster, G. (2000) *Phil. Trans. Roy. Soc. London Series A* **358**(1775): 2719-2740.



# TiO<sub>2</sub> Instillation in Rats - Surface Area

Oberdörster et al. (2000)

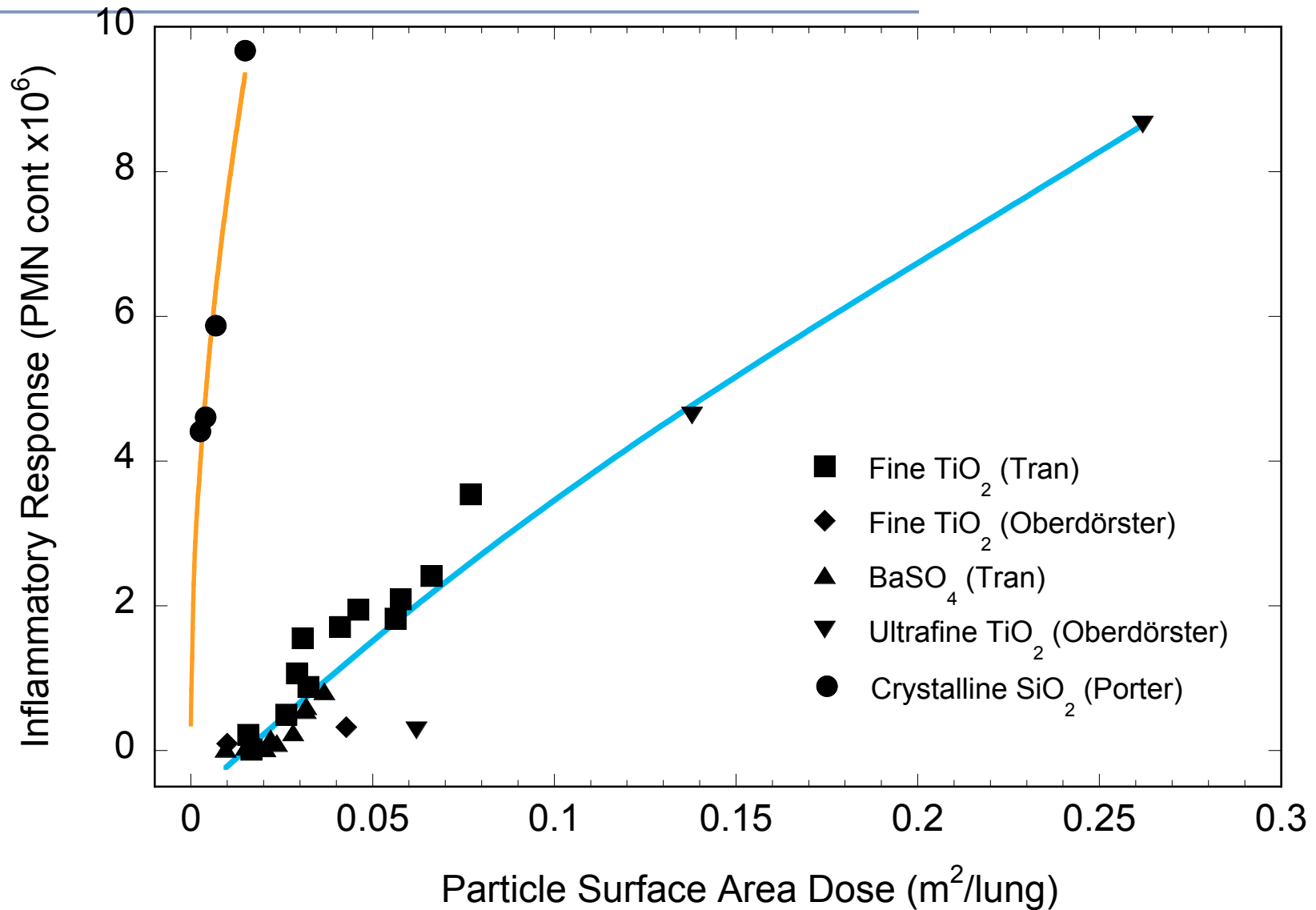


Oberdörster, G. (2000) *Phil. Trans. Roy. Soc. London Series A* **358**(1775): 2719-2740.



# Significance of Surface Activity

Comparison between low and high activity materials



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

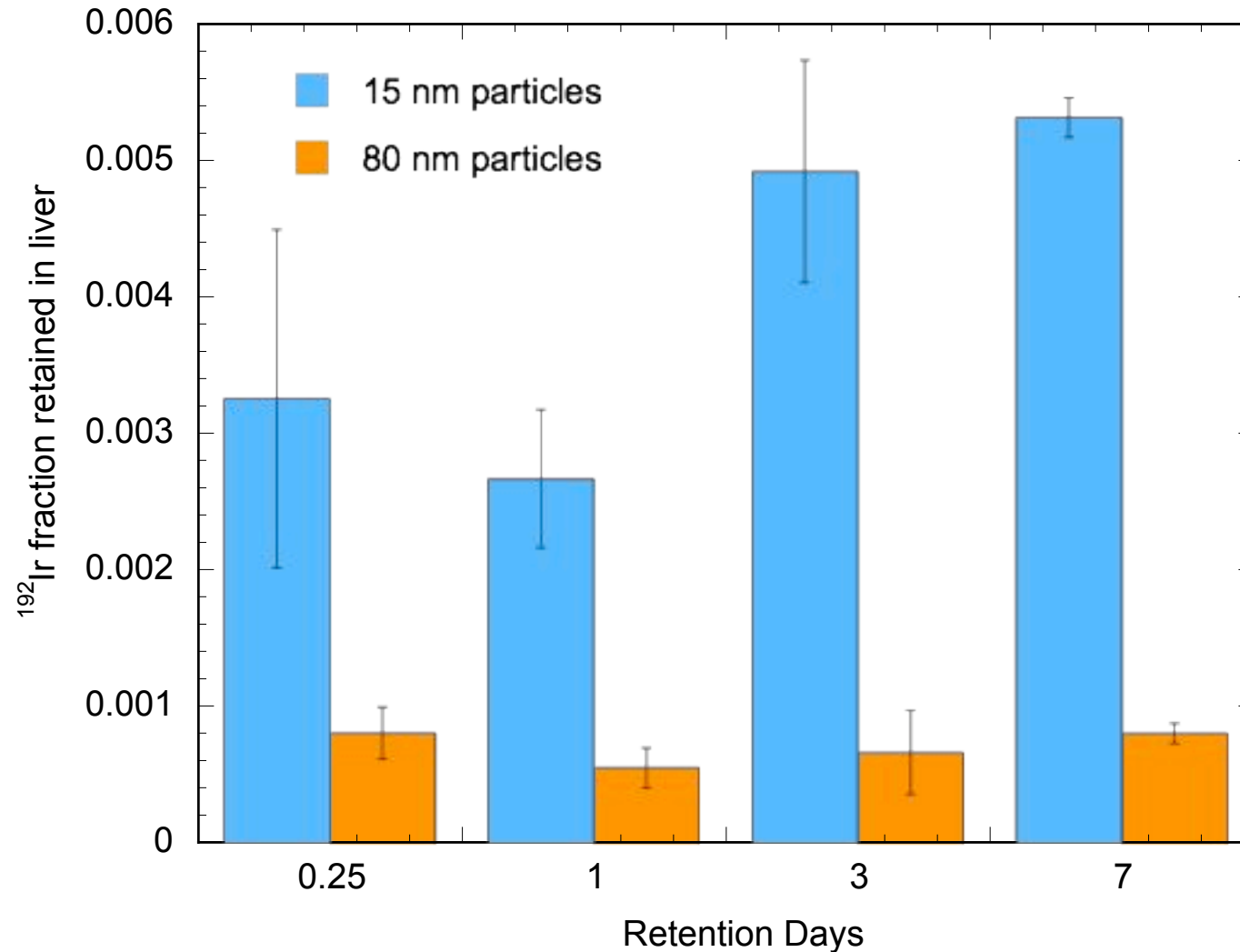




# Particle Size

## Translocation Following Inhalation - Lungs to Liver

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

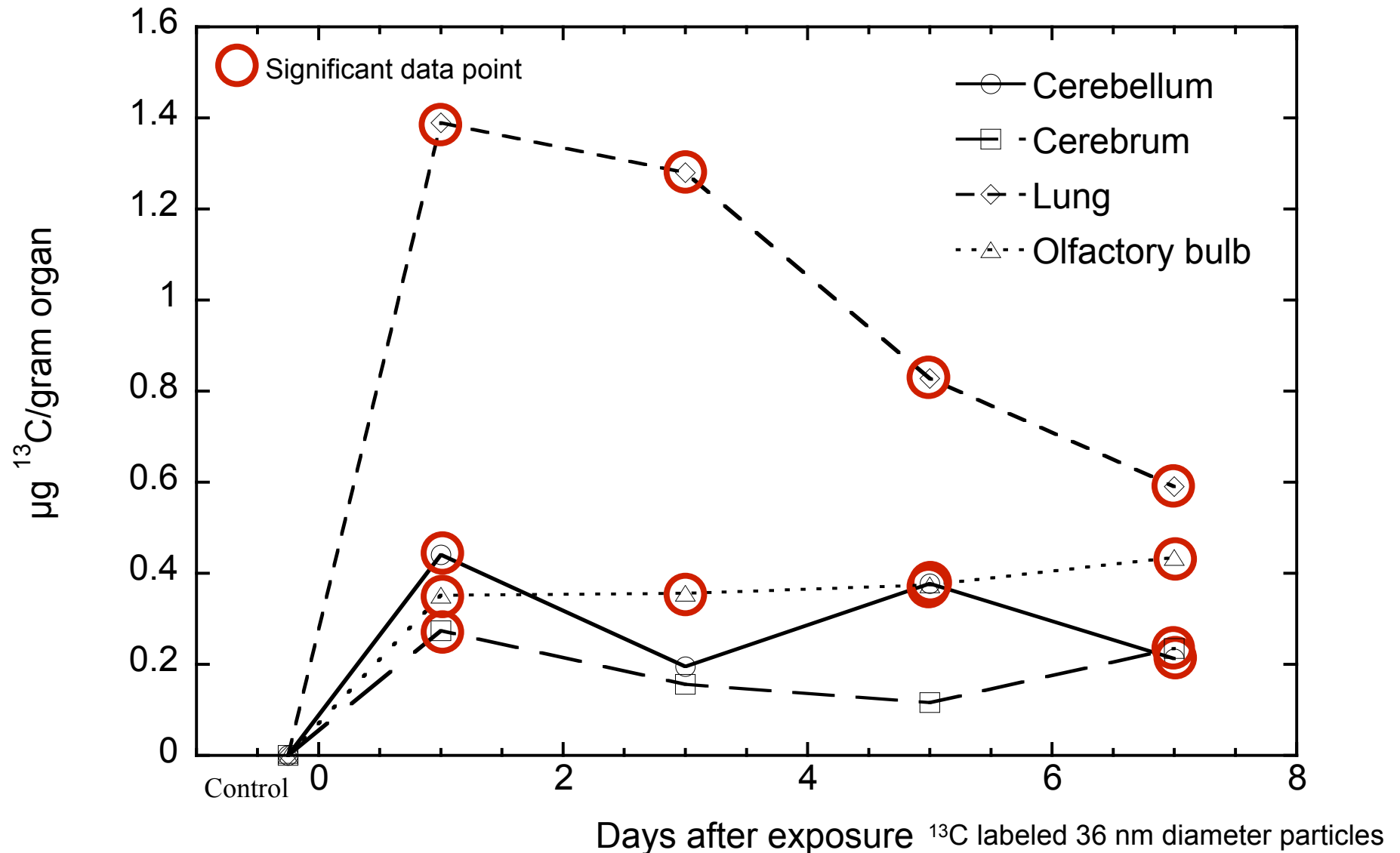


Kreyling, W. G. et al. (2002). *J. Toxicol. Env. Health Pt A* **65**(20): 1513-1530.



# Particle Size

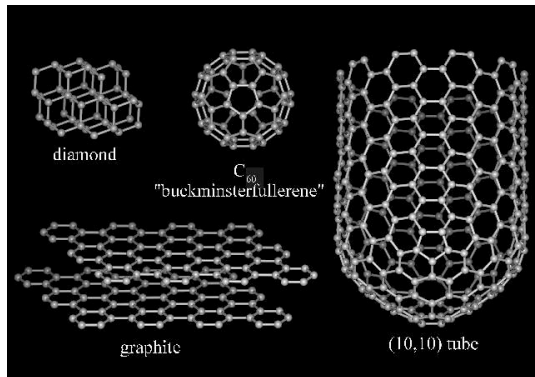
## Translocation Following Inhalation - Upper airways to brain



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



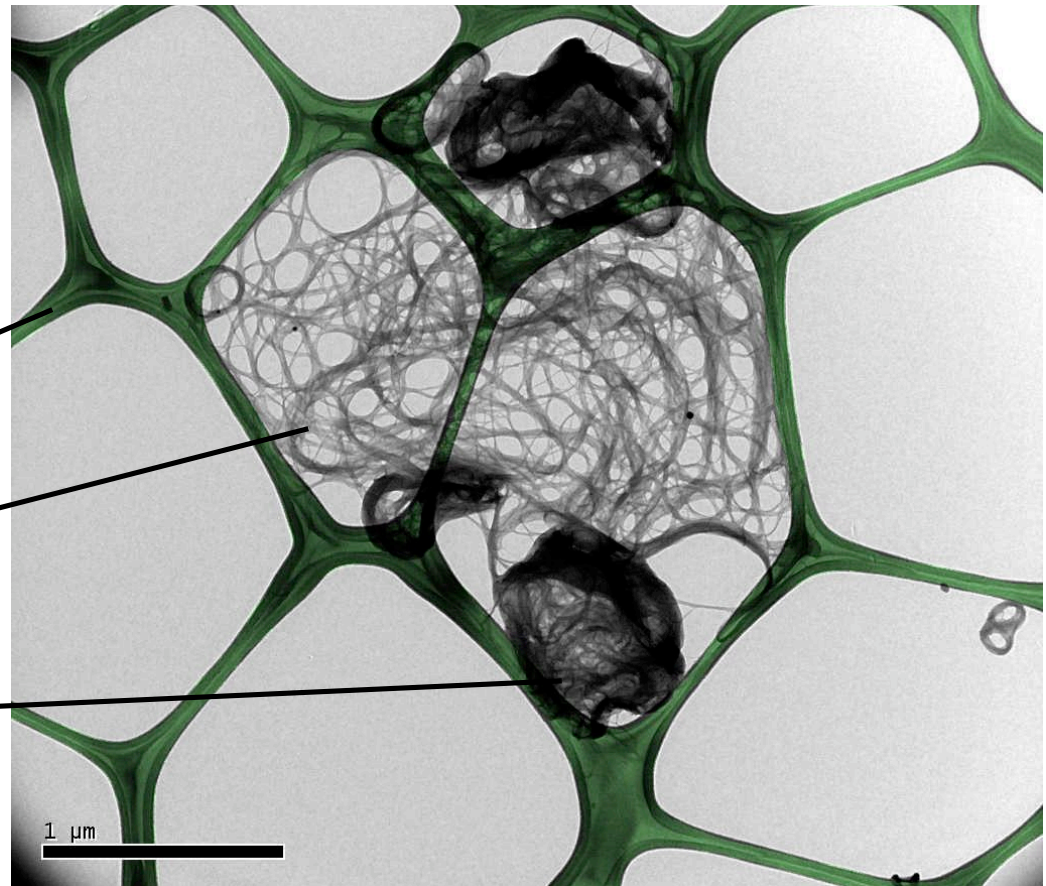
### Allotropes of carbon

Carbon support film

Open structured particles

Closed structured particles

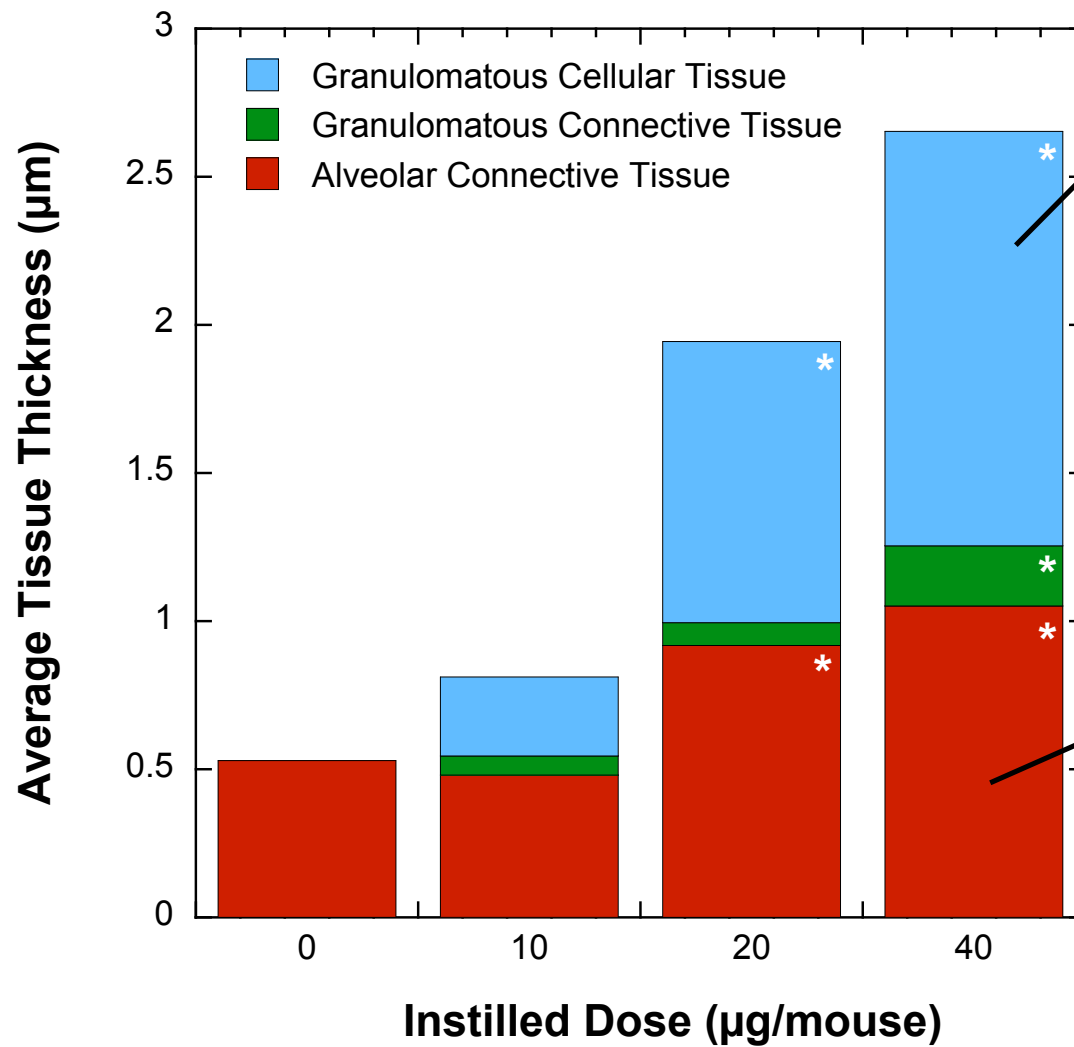
Transmission Electron Microscope image of purified single walled carbon nanotube particles



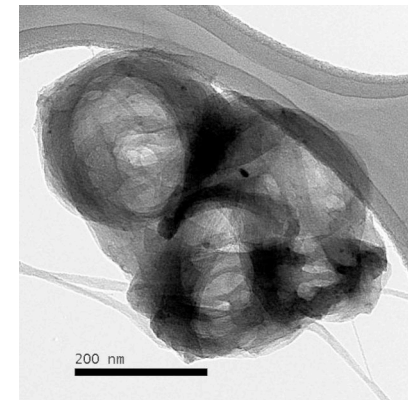
*Ku, Evans, Ramsey and Maynard, in Shvedova et al. (2005)*

# Single Walled Carbon Nanotubes

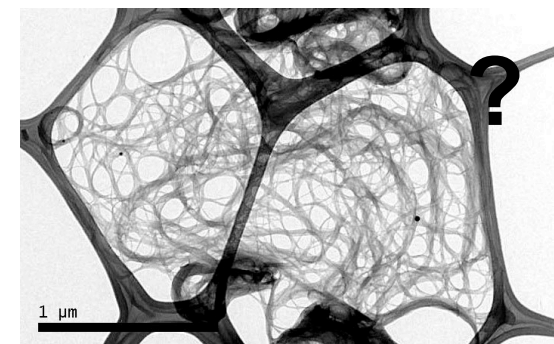
## Tissue thickening in mice - Pharyngeal aspiration



Proximal region of lung  
Visible SWCNT clumps

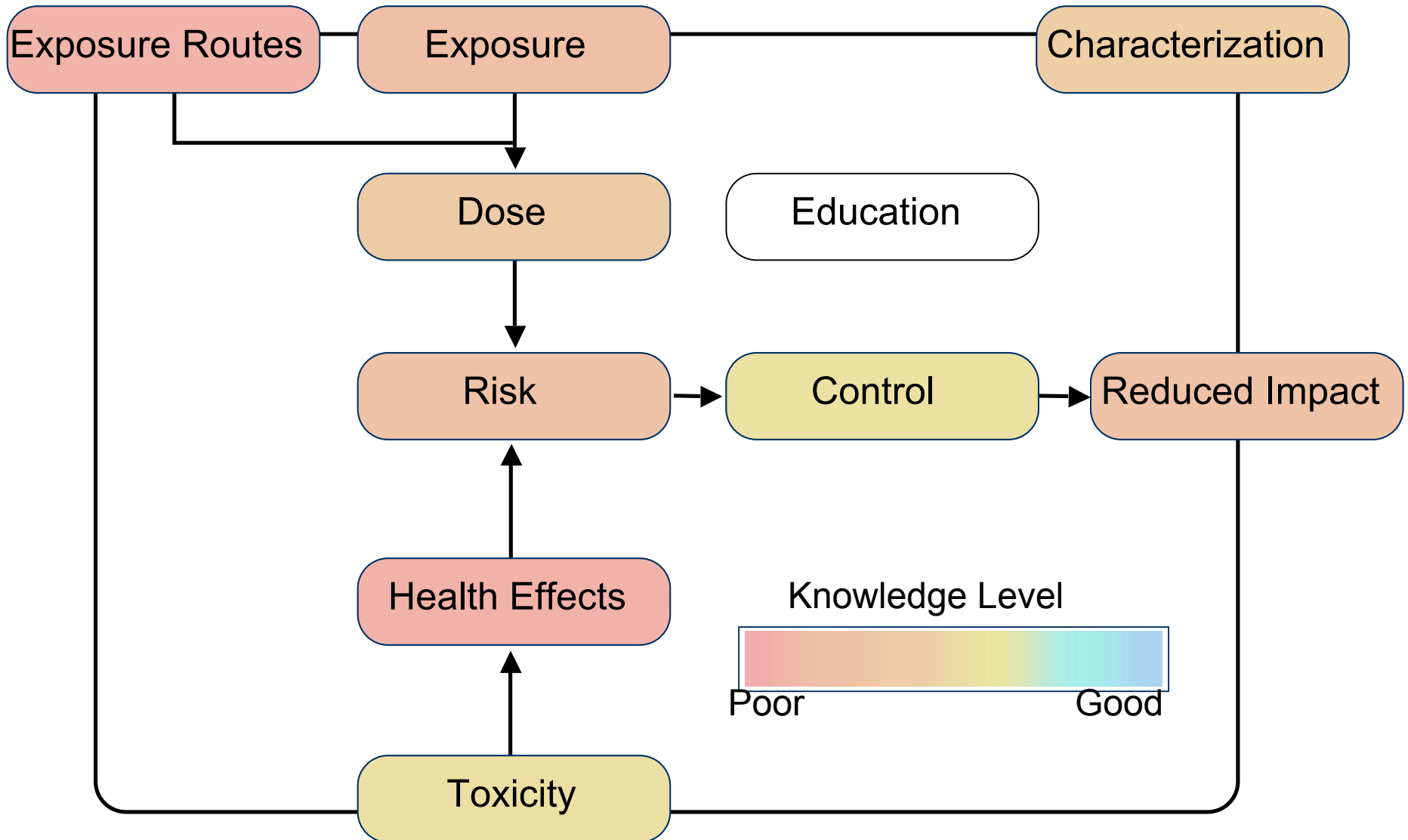


Distal region of lung  
No SWCNT visible



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

# Addressing Occupational Impact



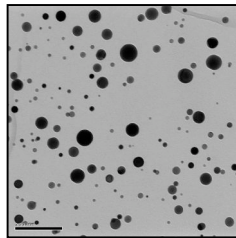




# Setting Boundaries

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



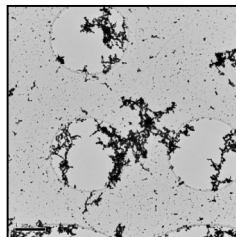
## Nanoparticles

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



## Comminution

Aerosols from grinding,  
cutting, machining  
nanomaterials



## Agglomerates

or aggregates of  
nanoparticles



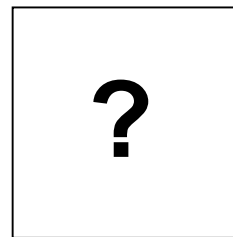
## Degradation/Failure

Aerosols and suspensions  
resulting from degradation  
and failure of nanomaterials



## Aerosolized suspensions

Including slurries and  
solutions of nanomaterials



## Unintentional use

Potential exposure from  
unanticipated/unintentional  
use



# Monitoring Nanoscale Aerosol Exposures

## Options

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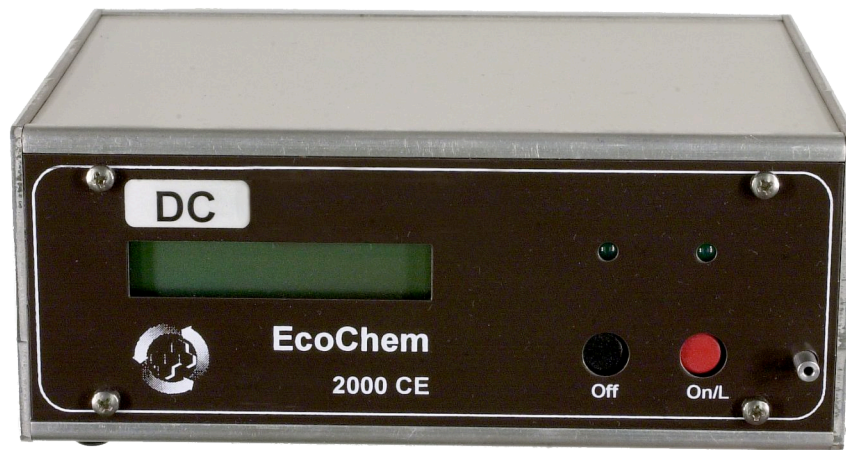
- Adapt current mass-based approaches
  - Continuity with the past
  - Sensitivity and relevance issues
- Measure size distribution
  - Provides a lot of information
  - Impractical in many instances
- Monitor number concentration
  - Relatively simple
  - Difficult to differentiate between process-related and background aerosols
  - Relevance?
- Monitor aerosol surface area concentration
  - Relevant for some materials. Is this achievable?

# Aerosol Surface-Area Measurement

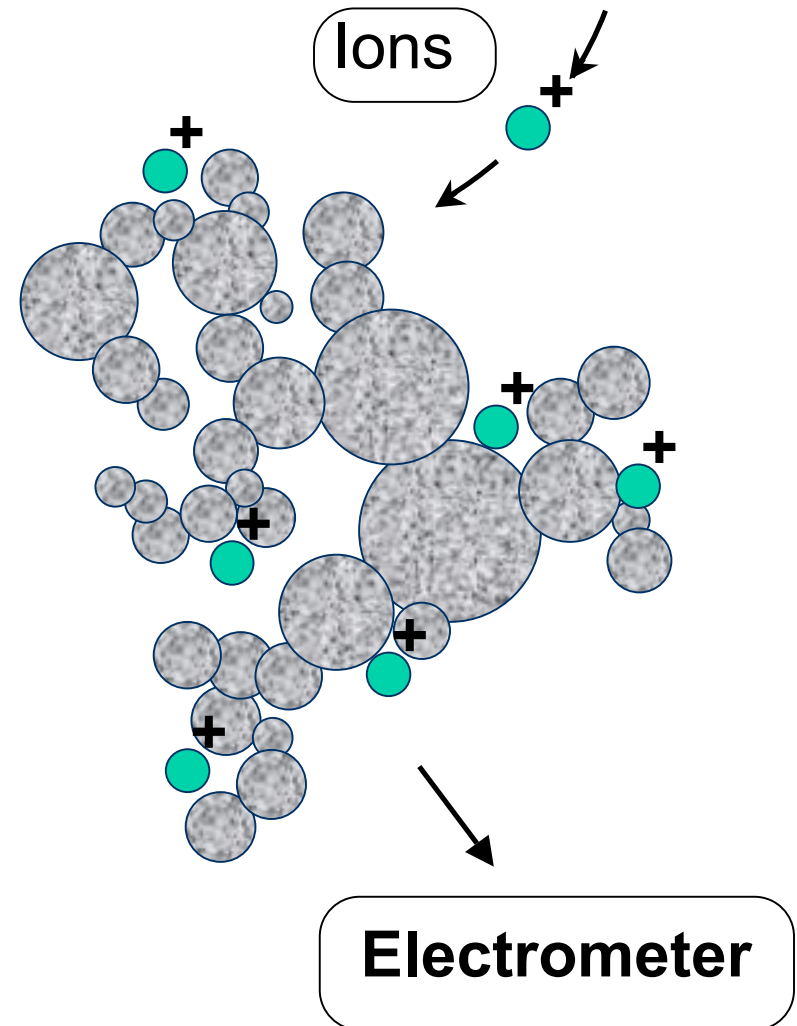
Using attachment rate



Charge on  $\propto$  Surface  
Aerosol Area

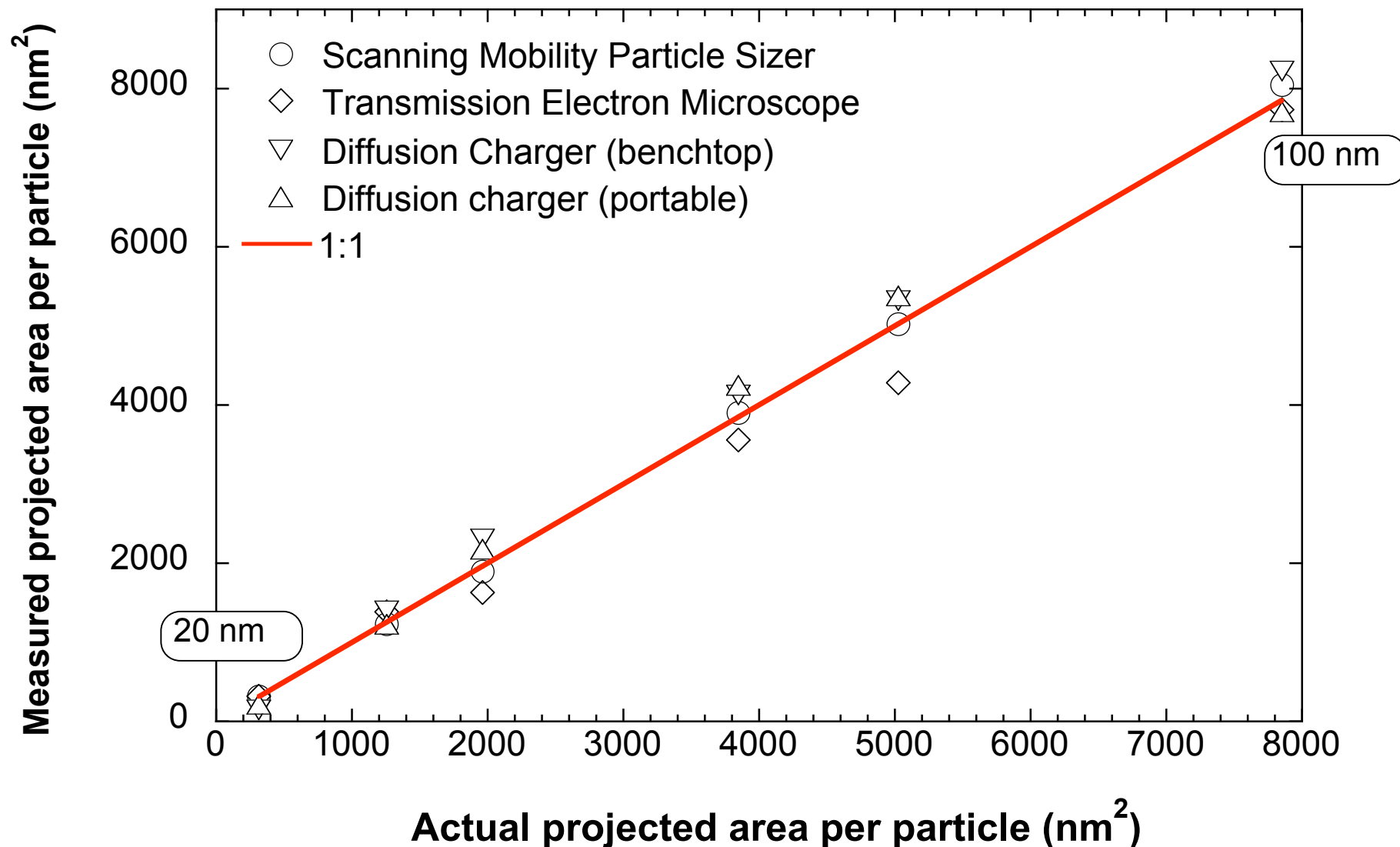
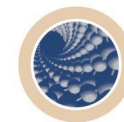


DC2000 CE Diffusion Charger  
*EcoChem*



# Comparison of Measurement Methods

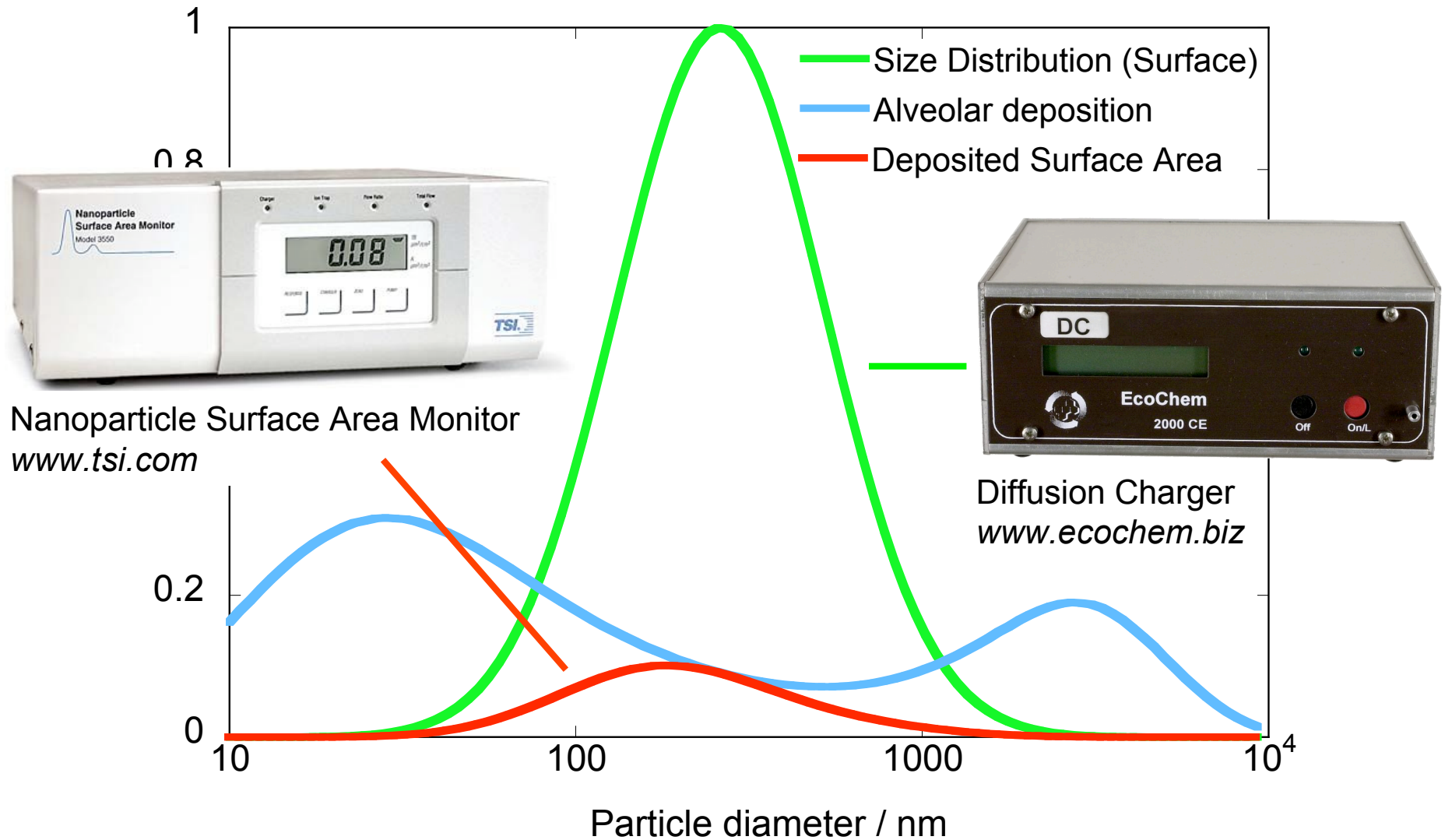
Monodisperse particles < 100 nm, fractal-like



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

# Emerging Measurement Technologies

## Deposited Surface Area



Wilson et al. (2004)





# Handling Nanotube Material

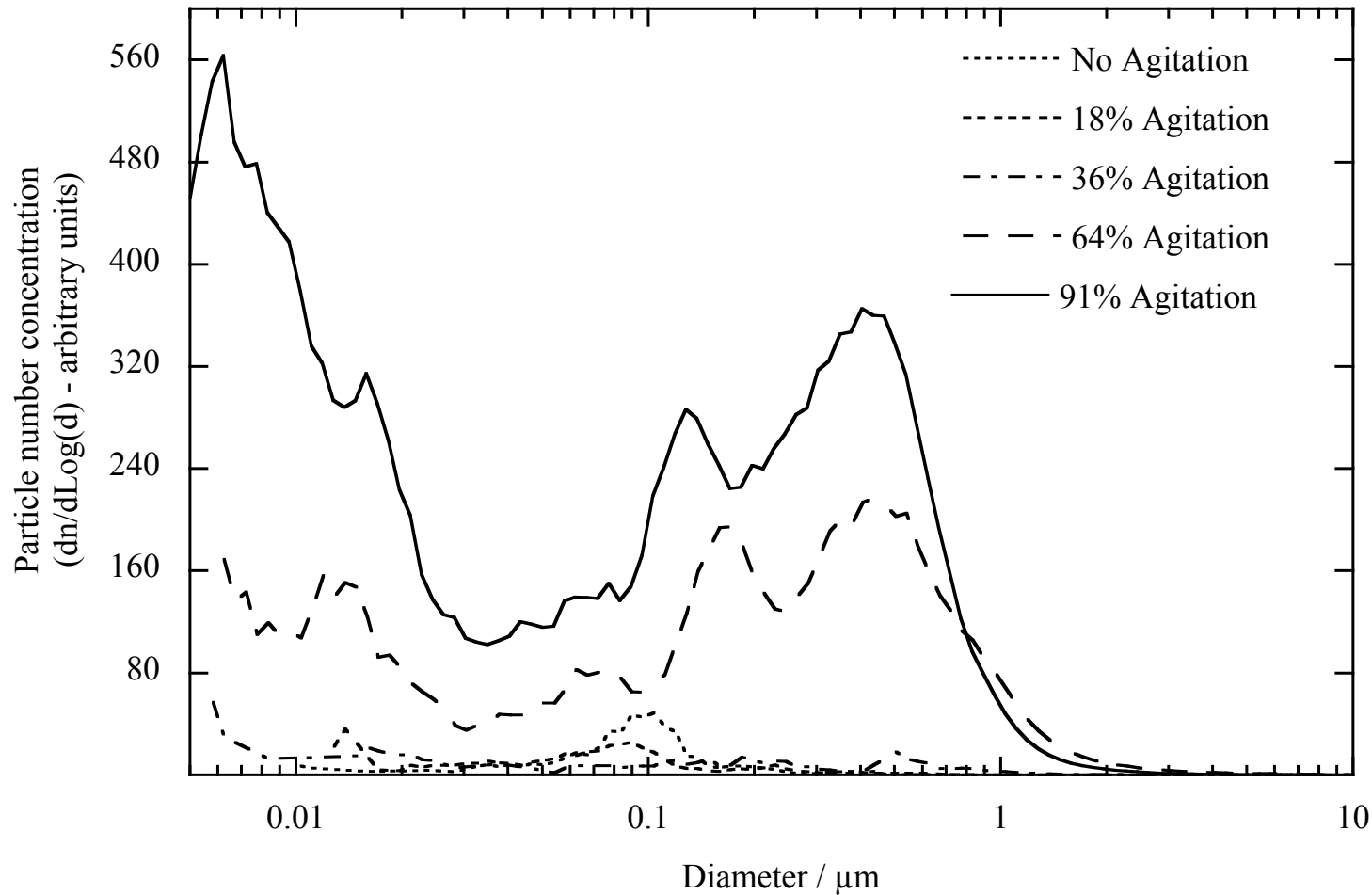
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**Unprocessed single walled nanotube material**



# Laboratory Generation of Nanotube Aerosol

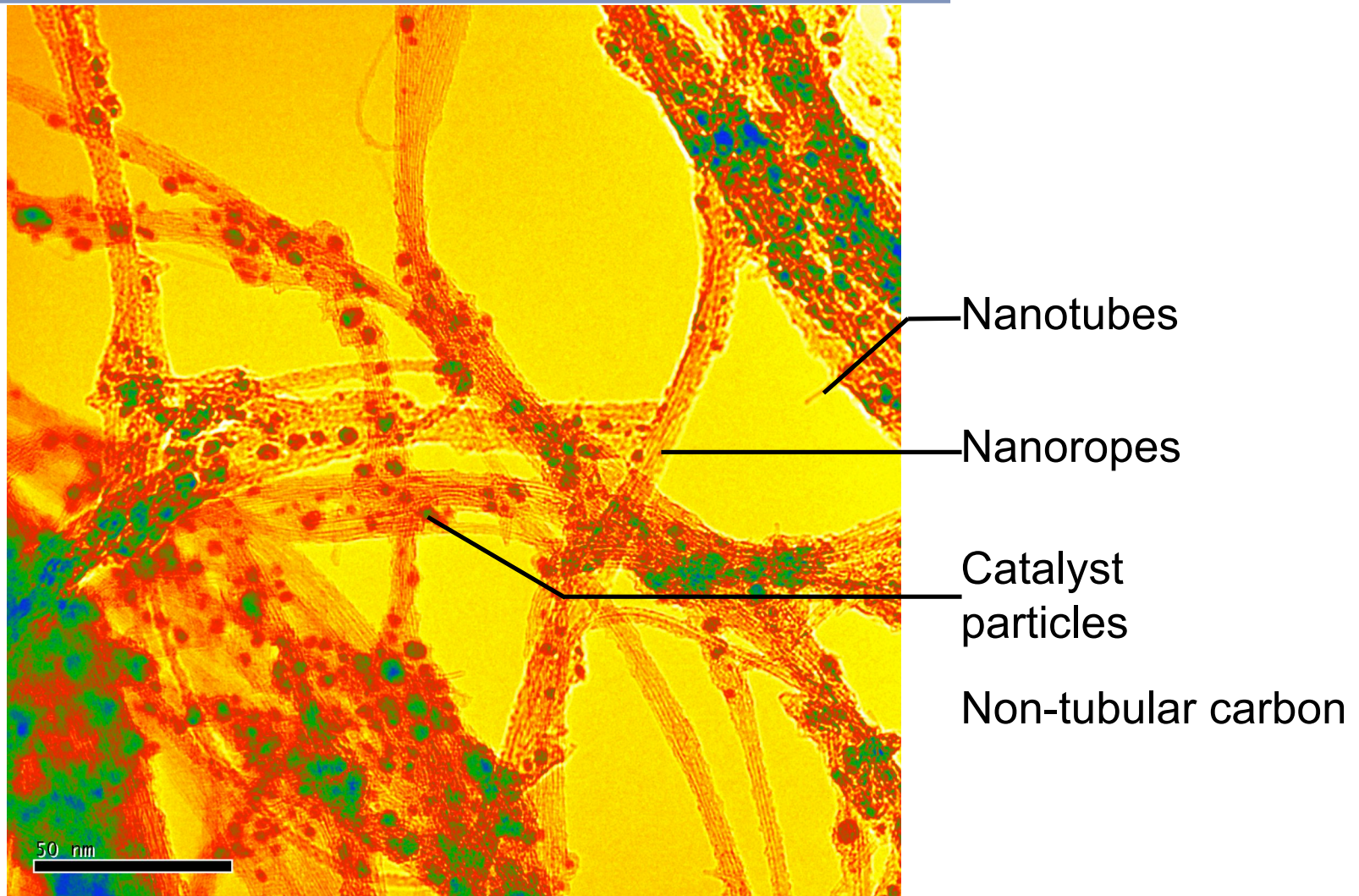


## Agitation of unprocessed material in an airflow

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

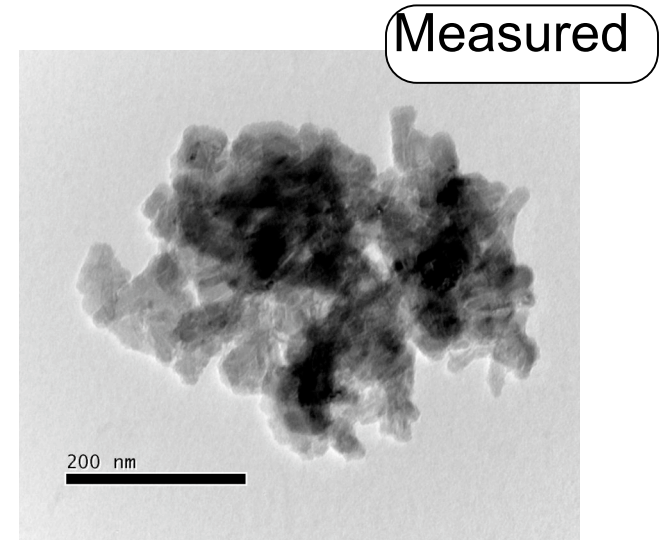
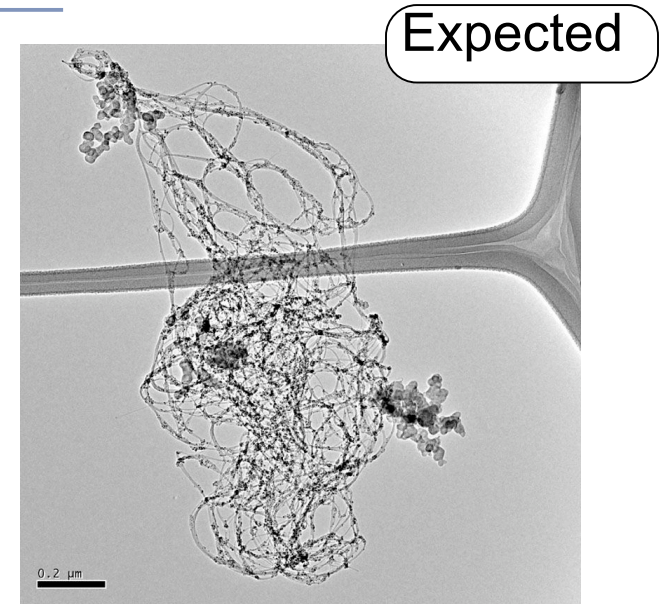
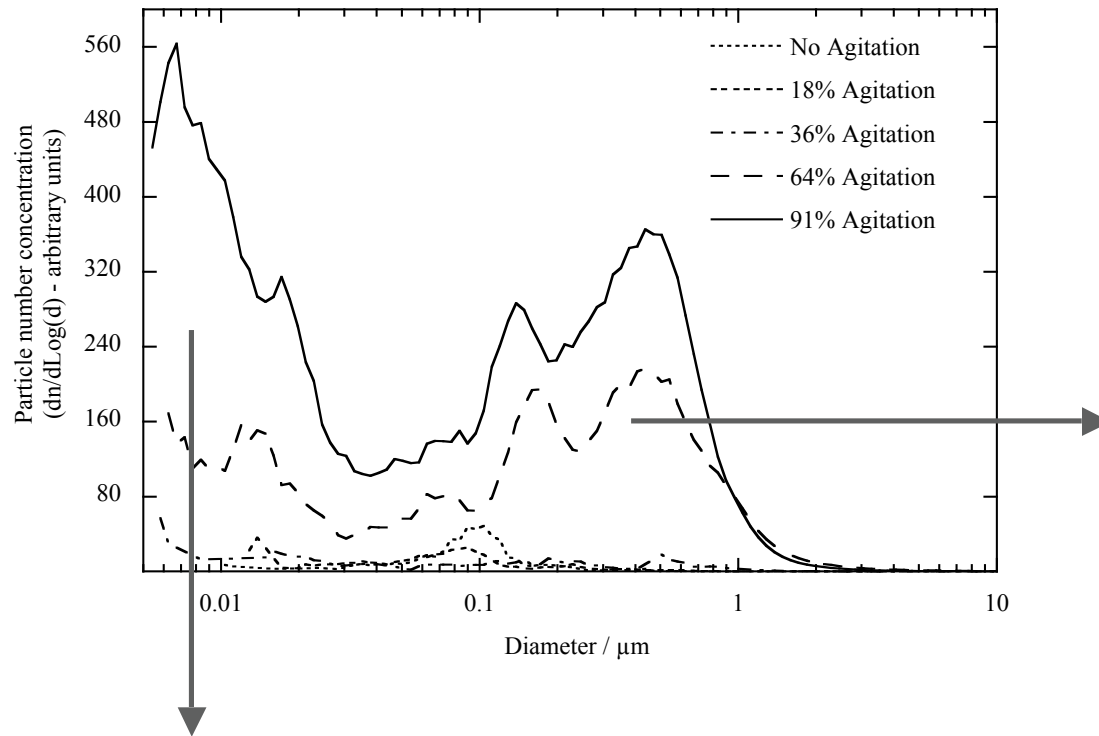


**Raw single walled carbon nanotube material.**





# Nanotube Aerosol Characterization



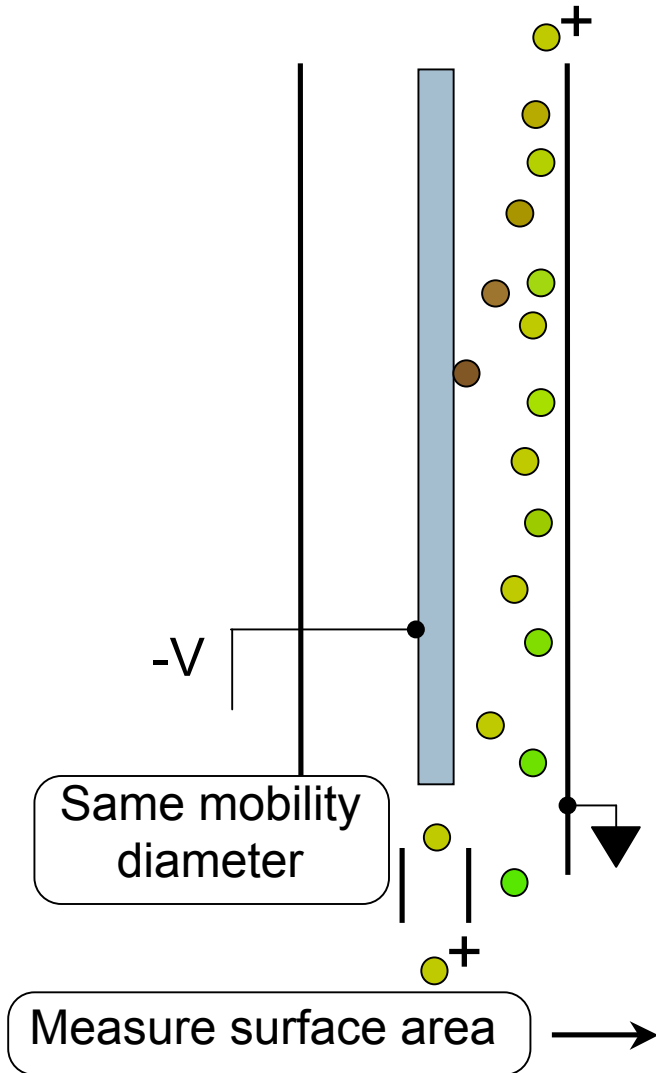
- **Physical/Chemical Characteristics?**
- Discrete carbon nanotubes or nanoropes?
- Transition metal catalyst particles?
- Non-tubular carbon?



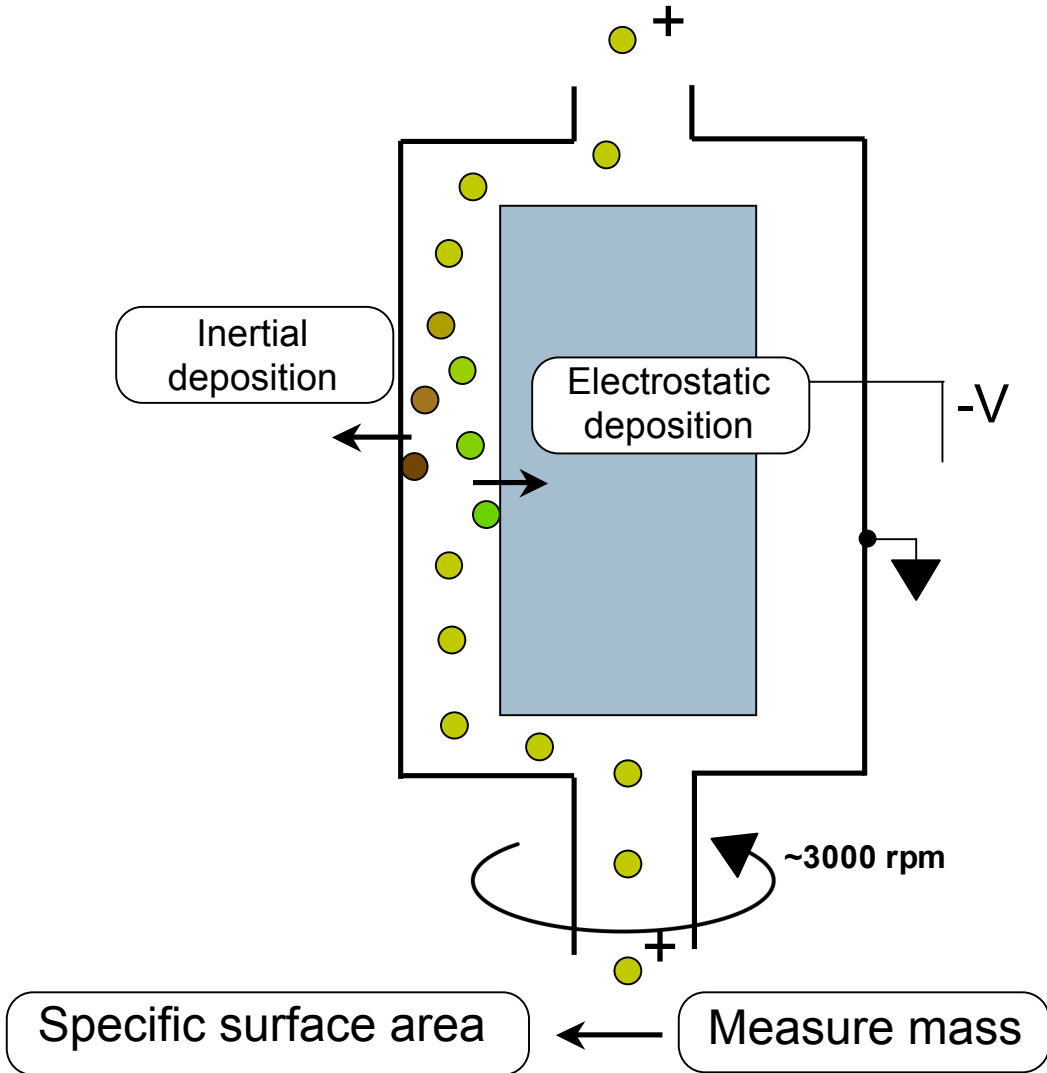
# Aerosol Characterization

'Active specific surface area' measurements

## Differential Mobility Analysis



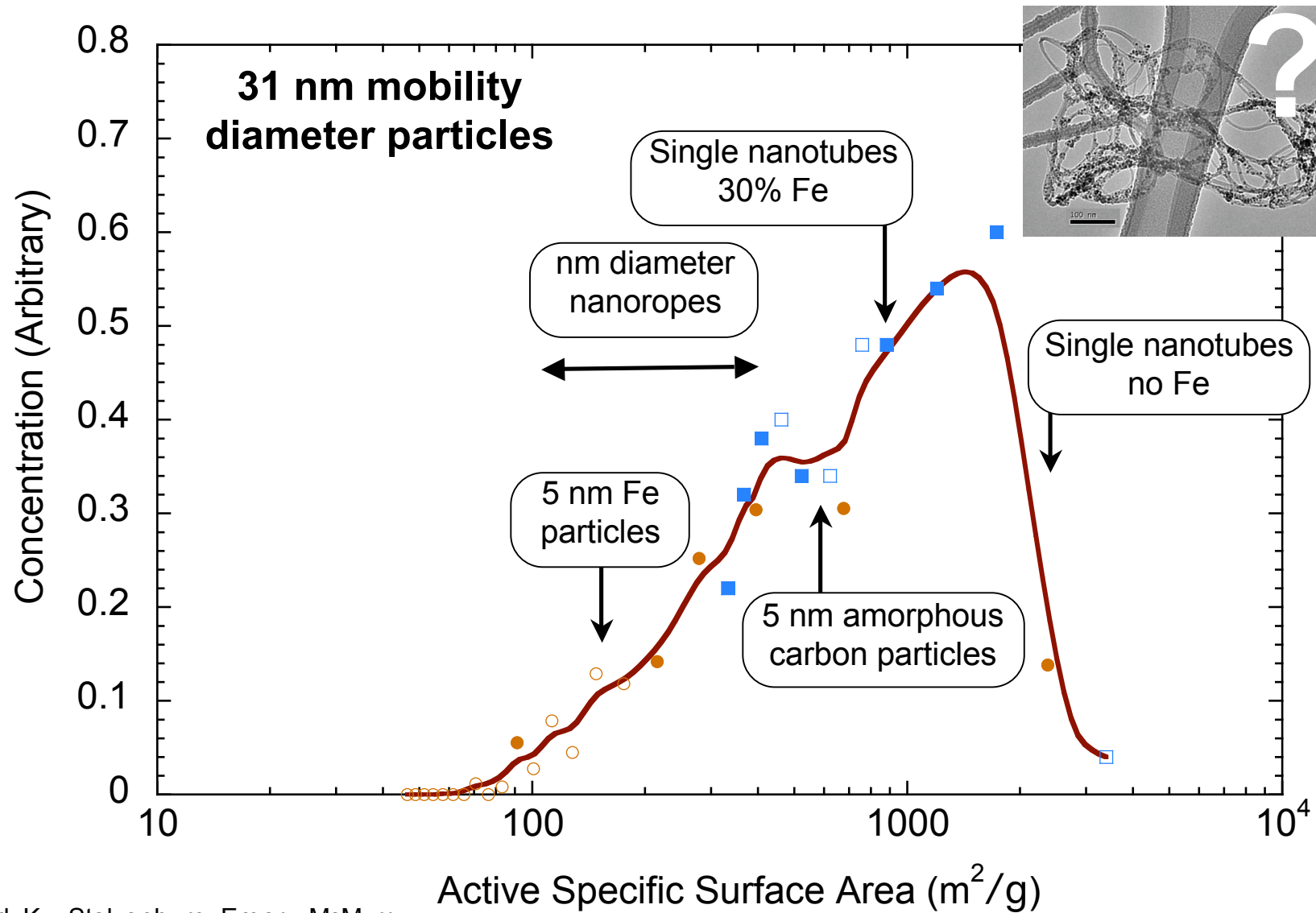
## Aerosol Particle Mass Analysis





# Aerosol Characterization

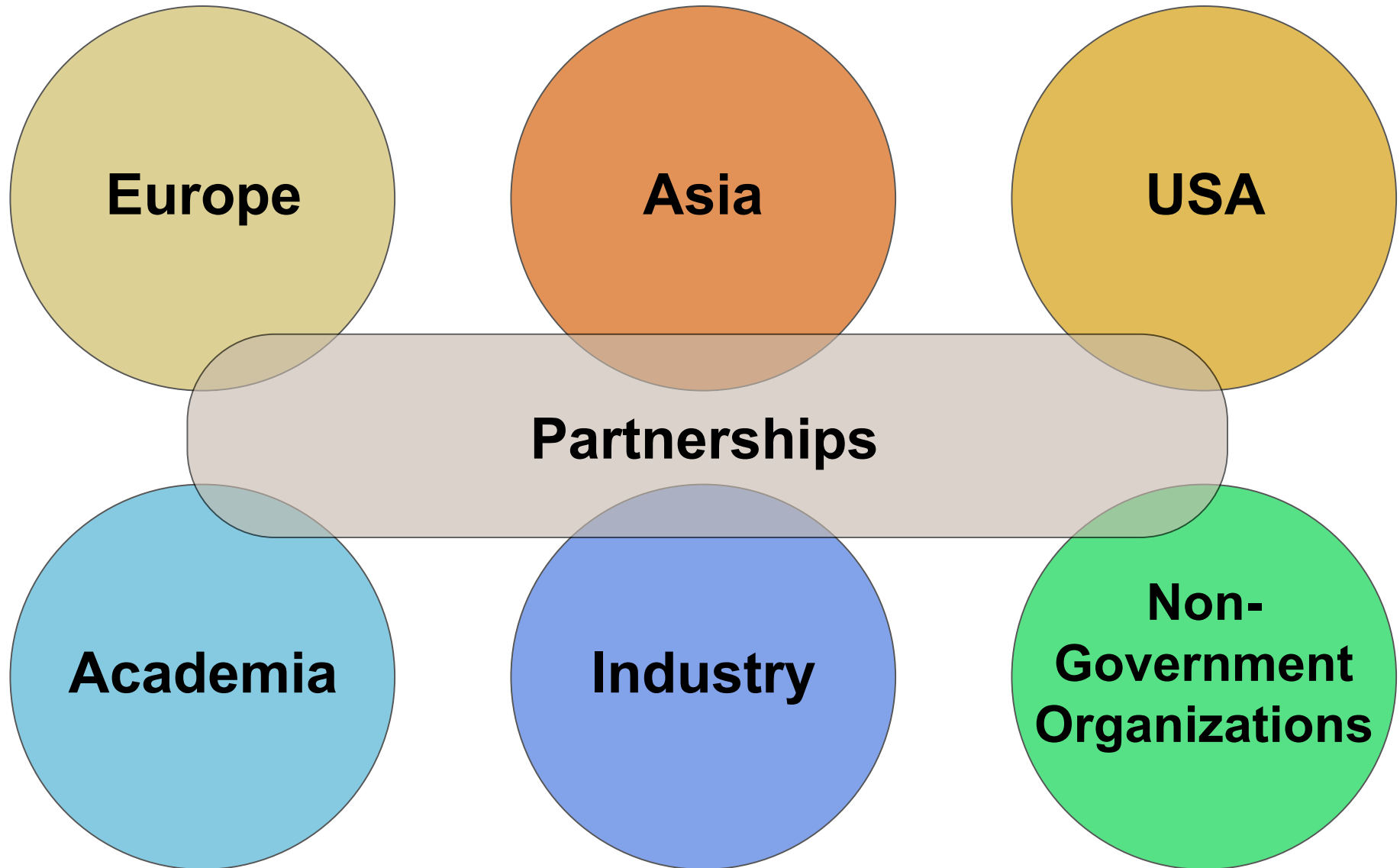
'Active' specific surface area



Maynard, Ku, Stolzenburg, Emery, McMurry

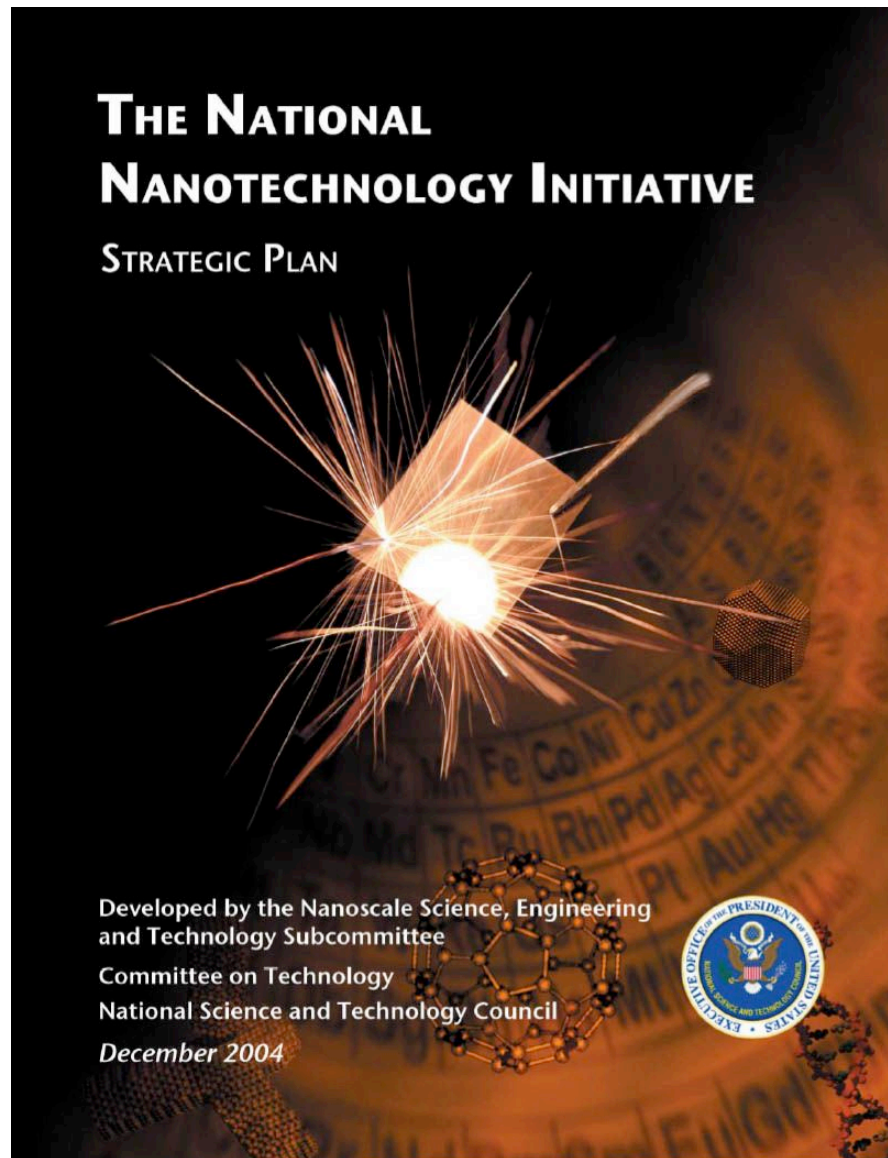
# Impact of Engineered Nanomaterials

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](http://www.nano.gov)

# Working with Engineered Nanomaterials

## NIOSH

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**NIOSH** National Institute for  
Occupational Safety and Health


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NIOSH Safety and Health Topic:

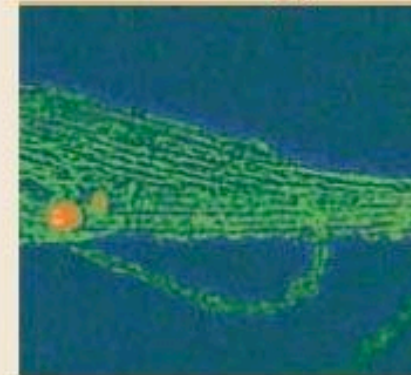
## Nanotechnology

### 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



[Nanotechnology Home](#)

[Approaches to Safe  
Nanotechnology: An  
Information Exchange with  
NIOSH](#)


[www.cdc.gov/niosh/topics/nanotech/strat\\_plan.html](http://www.cdc.gov/niosh/topics/nanotech/strat_plan.html)



# Working with Engineered Nanomaterials

## NIOSH



 **NIOSH** National Institute for Occupational Safety and Health

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### NIOSH Safety and Health Topic:

## Nanotechnology

### Approaches to Safe Nanotechnology: An Information Exchange with NIOSH

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#### Director's Message

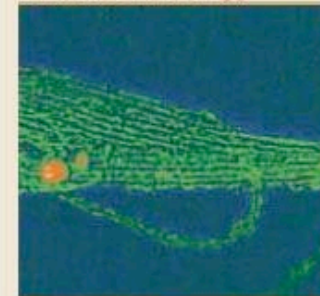
The field of nanotechnology is advancing rapidly and will likely revolutionize the global industry. As with any new technology, we are faced with many unknowns; all of which raise questions concerning occupational safety and health. The National Institute for Occupational Safety and Health (NIOSH) is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

#### Nanotechnology



#### Topic Index:

[Nanotechnology Home](#)

▶ [Approaches to Safe Nanotechnology: An Information Exchange with NIOSH](#)

[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](http://www.cdc.gov/niosh/topics/nanotech/nano_exchange.html)

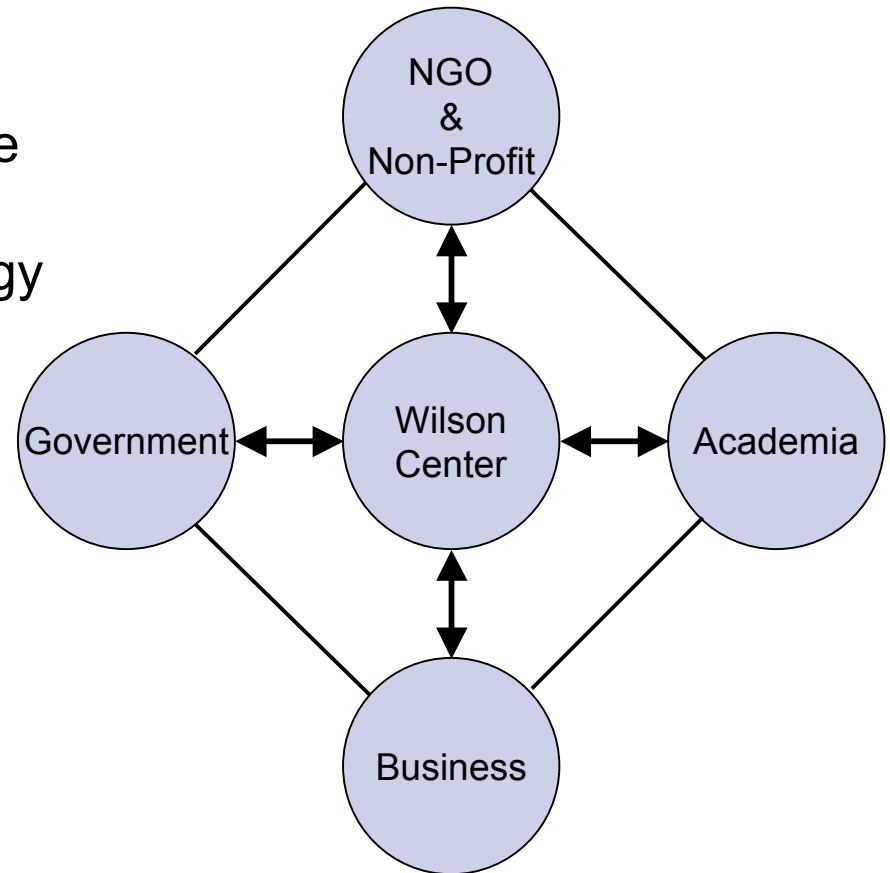


# Project on Emerging Nanotechnologies

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](http://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

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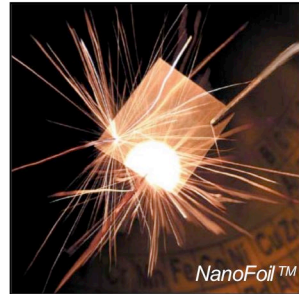
- Nanotechnology is a revolutionary technology
- Significant societal and economic benefits are anticipated
- Conventional risk management models are being challenged
- Successful development and implementation of nanotechnology will require an integrated approach to risk
- Global, interdisciplinary and cross-sector partnerships are essential to developing sustainable nanotechnologies



# Looking to the Future

Moving beyond the health impact of 'simple' nanomaterials

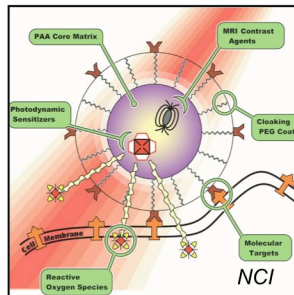
Photo by Maximilian Franz, courtesy of Reactive nanotechnologies Inc.



## Safety

“Unconventional” and unanticipated behavior

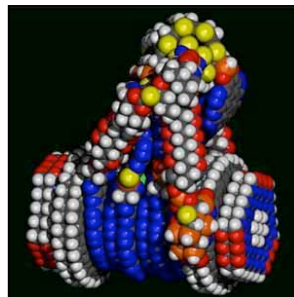
Kopeiman & Philbert, UMich



## Complex nanoparticles and nano-devices

Moving beyond simple response mechanisms

Institute for Molecular Manufacturing  
[www.imm.org](http://www.imm.org)



## Convergence

Revolutionary Health & Safety Challenges

[www.liftport.com](http://www.liftport.com)



# Contact Information

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