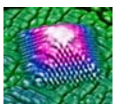
REUSE IN RHODE ISLAND
A State-Based Approach To Complex Exposures
BROWN

Nanotechnology – Human Health and Environmental Impacts

Jim Rice, Robert Hurt, Agnes Kane

Brown University, Providence, Rhode Island

NEWMOA Webinar, January 24th, 2012



Institute for Molecular and Nanoscale Innovation

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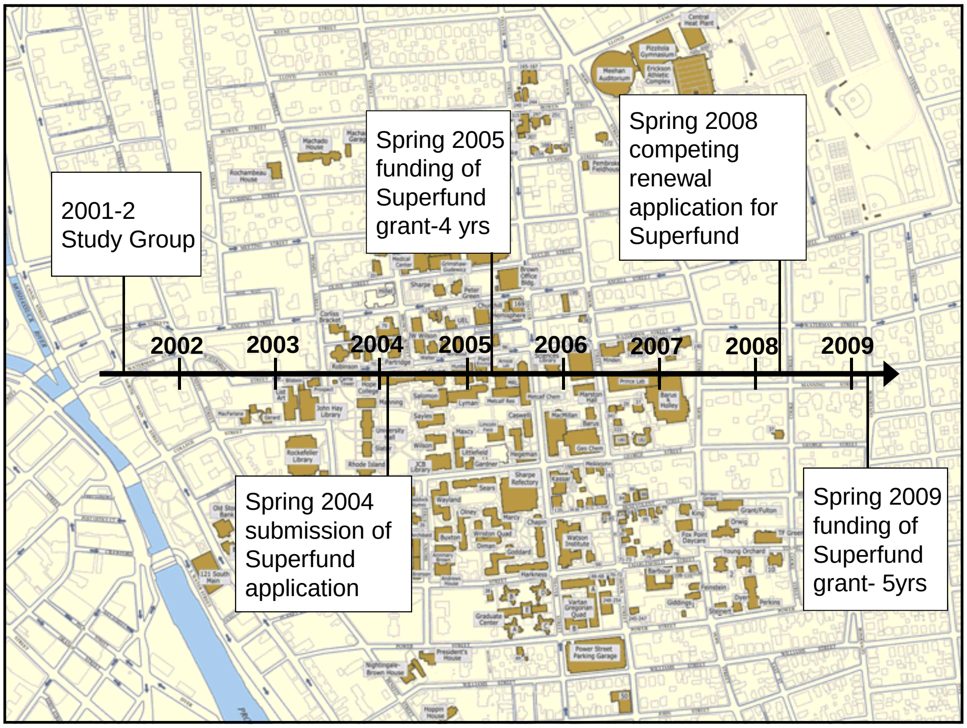
The Superfund Research Program at Brown University

Rhode Island is Our Laboratory

Mission - To provide Rhode Island (and other states) with a responsive center of technical excellence that takes a research-oriented approach to resolving the complex scientific, engineering, and societal issues that arise when considering the reuse of hazardous waste sites

- **Focus on Mixed Exposures**
  - Environmental health and engineering research
  - Technology development
- **4 Biomedical and 3 Engineering Research Projects**
  - Tackle reuse of contaminated land in RI and other post-industrial states
  - Seek to understand the health effects of complex exposures
  - Focus on **Nanotechnology & Metals**, **Molecular Epidemiology & Reproduction**, and **Semi-Volatile Organics & Vapor Intrusion**
- **Research Translation and Community Engagement Cores**
  - Provide knowledge and services to professional and community stakeholders
  - Address basic and translational research issues, management decisions, and communication complexities inherent to reuse of hazardous waste sites


2001-2
Study Group
Spring 2005
funding of
Superfund
grant-4 yrs
Spring 2008
competing
renewal
application for
Superfund
2002
2003
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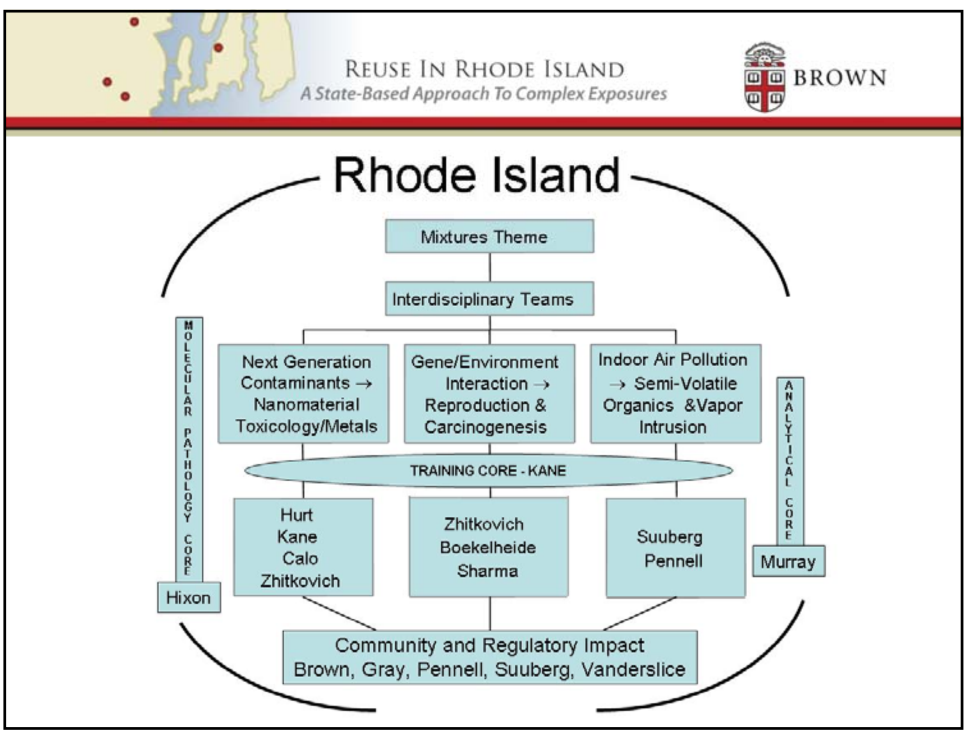
2008
2009
Spring 2004
submission of
Superfund
application
Spring 2009
funding of
Superfund
grant- 5yrs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Rhode Island
Mixtures Theme
Interdisciplinary Teams
Next Generation Contaminants → Nanomaterial Toxicology/Metals
Gene/Environment Interaction → Reproduction & Carcinogenesis
Indoor Air Pollution → Semi-Volatile Organics &Vapor Intrusion
MOLECULAR PATHOLOGY CORE
Hixon
ANALYTICAL CORE
Murray
TRAINING CORE - KANE
Hurt
Kane
Calo
Zhitkovich
Zhitkovich
Boekelheide
Sharma
Suuberg
Pennell
Community and Regulatory Impact
Brown, Gray, Pennell, Suuberg, Vanderslice

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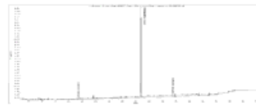
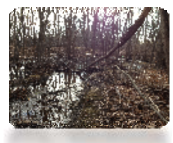
Partnerships at Regional NPL Sites



- Fisherville Mill NPL Site, Grafton, MA
  - In partnership with our Analytical core, the Fisherville Redevelopment Company, and Clark University, Jim Rice leads an effort aimed at helping to develop an efficient and reliable analytical testing method to determine whether bioremediation efforts are improving water quality in the Blackstone River.



- Centredale Manor NPL Site, N. Providence, RI
  - Attended October 2011 Dialogue Group Meeting with EPA, RI DEM, RI DOH, community activists, lawyers, etc.
  - Exploring opportunities for research; interested in partnering with Narragansett EPA labs to determine how remediation activity influences bioavailability of sediment contaminants
  - Partnering with WRWC through Community Engagement Core efforts – Questions about the Oxbow area; community education and risk communication; and what is happening downriver?

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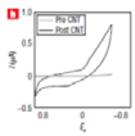
How Can You Interact With Us?

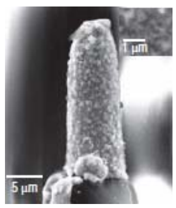
- **We provide/seek two-way professional to professional communication of relevance**
  - Official State partners (Rhode Island Departments of Heath and Environmental Management)
  - Other non-governmental partners (RI Bar Association, NEWMOA, Metcalf, etc.)
- **We host translational seminars, conferences, webinars, symposiums. For example:**
  - ***Addressing the Complex Site: Mixed Pollutants Across Environmental Media*** Symposium at the American Chemical Society National Meeting (Fall 2012)
  - ***Social, Economic, and Psychological Costs of Contamination*** Workshop (May 2012)
  - ***Fate and Transport and Toxicology of Nanomaterials*** Webinar co-sponsored by NEWMOA (Jan. 2012)
  - ***Epigenetics and Fetal Origins of Heath and Disease*** Symposium (Oct. 2011) - 79 attendees (DOH, academia, healthcare, non-profits); 23 RNs awarded continuing education credits
  - ***Environmental Health and Chemical Exposures: Law and Science*** Seminar co-sponsored by The RI Bar Association (2010)
  - ***Waiter, there's a phthalate in my soup! Reporting on the Science & Impacts of Toxic Chemicals*** Seminar for journalists co-sponsored by Metcalf Institute for Marine & Environmental Reporting (2010)
- **We aim to involve our investigators & students in translational research/communication activities.**
  - Monthly seminar series
  - Planning informal lunches with State partners, i.e., RIDEM and RIDOH
  - We would like to get students more engaged with actual hazardous waste sites
- **We search for creative and practical research activities and funding opportunities/partnerships.**
- **Contact Us:**
  - Website http://www.brown.edu/Research/SRP/
  - James Rice, PhD, Engineering State Agencies Liaison, James_Rice@brown.edu

nature
nanotechnology

Carbon nanotube coating
improves neuronal recordings

Keefer et al., 2008



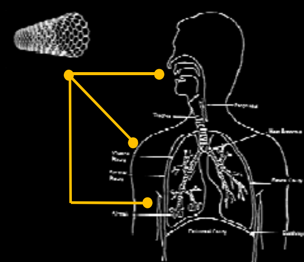


Janus

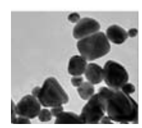
The New York Times

In Study, Researchers Find
Nanotubes May Pose Health
Risks Similar to Asbestos

May 21, 2008



The Nanotechnology Movement

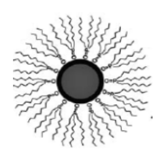


Definition

the systematic manipulation of matter on the length scale 1-100 nm
to produce useful new engineered structures, materials, or devices.

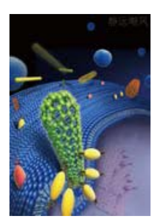
History

- R. Feynman, 1959, "There's plenty of room at the bottom"
- Kroto, Smalley, Curl, Fullerene C60 synthesis, 1985
- Sumio Iijima, 1991, nanotube synthesis



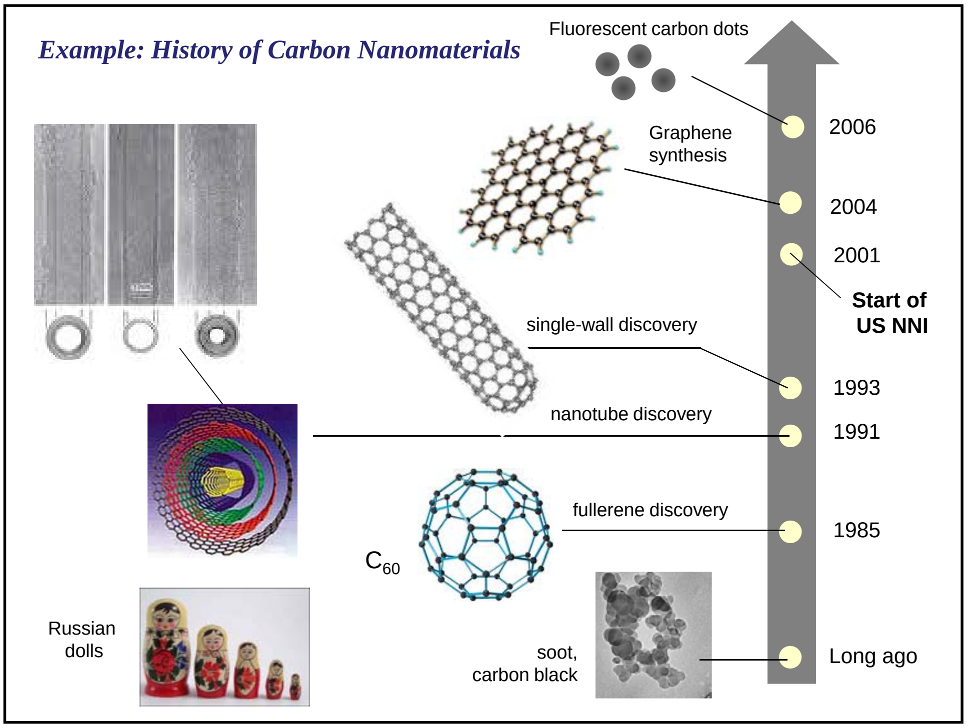
Nanotechnology today

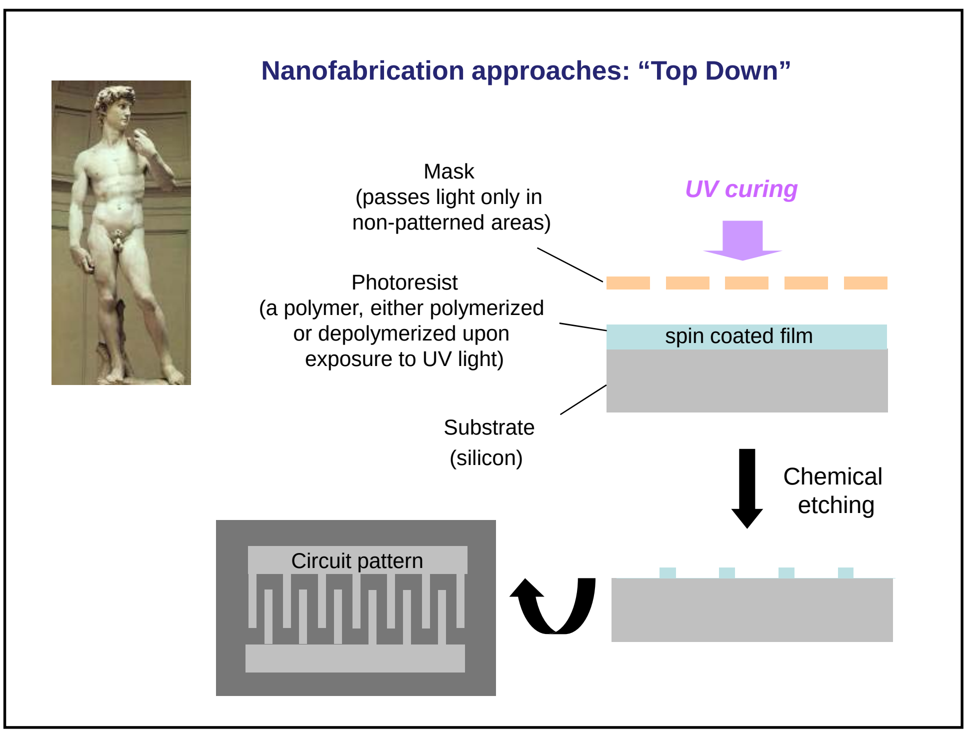
- over 60,000 scientific papers / yr
- over 1,300 industrial products (as of 2010)



The U.S. National Nanotechnology Initiative (NNI)

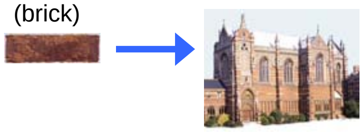
- first passed in 2001, reauthorized in 2008
- now ~ 2.1 billion $ / yr (2012)
- four phases envisioned:
    1. passive nanostructures
    2. active nanostructures
    3. three dimensional nanosystems
    4. molecular nanosystems


Example: History of Carbon Nanomaterials
Fluorescent carbon dots
Graphene
synthesis
2006
2004
2001
Start of
US NNI
single-wall discovery
1993
nanotube discovery
1991
fullerene discovery
1985
C60
Russian
dolls
soot,
carbon black
Long ago


Nanofabrication approaches: "Top Down"
Mask
(passes light only in
non-patterned areas)
UV curing
Photoresist
(a polymer, either polymerized
or depolymerized upon
exposure to UV light)
spin coated film
Substrate
(silicon)
Chemical
etching
Circuit pattern

Nanofabrication approaches: "Bottom Up"

(brick)

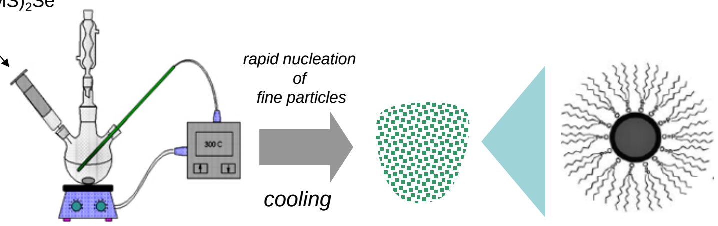


Bottom-up, or self-assembly, approaches use chemical or physical forces operating at the nanoscale to assemble basic units into larger structures.

Inspiration for bottom-up approaches comes from the biological world, which self-assemble into complex systems that even replicate and evolve.

Example

organometallic reagents, e.g. Me_2Cd, $(TMS)_2Se$



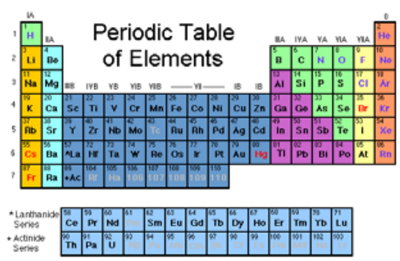
preheated coordinating solvent e.g. tri-octadecylphosphine (TOP)

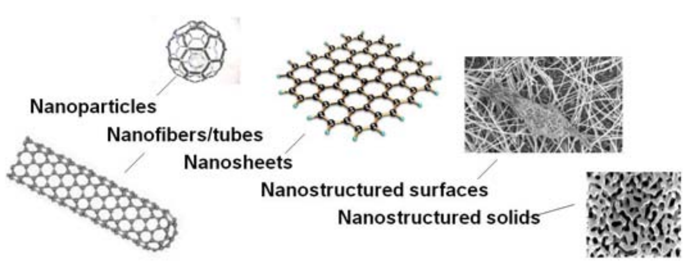
Most nanoparticles have "coatings" that stabilize them and limit growth

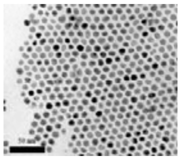
Nanomaterials Today

Geometry x Chemistry = almost limitless diversity, complexity

- Equi-axed forms (nanoparticles)
- One-dimensional forms (fibers and tubes)
- Two-dimensional forms (plates and disks)
- Nanostructured surfaces
- Nanostructured solids





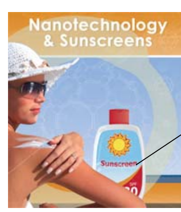


Some specific examples of nanomaterials

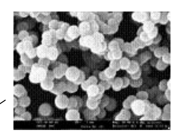
	Equi-axed forms (particles)	1D materials (fibers, tubes)	2D materials (plates, disks)
metals	Silver, gold nanoparticles Iron, cobalt, nickel magnetic nanoparticles copper nanoparticle conducting inks	nanowires	
semiconductors	CdSe quantum dots	Si, ZnO semiconducting nanowires, nanorods	
ceramics	zinc oxide, titanium dioxide pigments and sun screens, cerium oxide catalysts	electrospun ceramic nanofibers for composite fillers	nano-clays
carbons	fullerenes, carbon black, nanohorns	carbon nanotubes nanofibers	graphene few-layer graphene graphene oxide
polymers	biodegradable polymer nanobeads for medical applications, dendrimers	electrospun polymer nanofibers	

Nanotechnology in Industry

Now (1,300 products)



Metal oxides



Components for next-generation batteries, fuel cells, computer chips, displays, structural materials, cosmetics, implants, drug delivery vehicles, paints, self-cleaning windows, and much, much more…….

The Woodrow Wilson Center "Project on Emerging Nanotechnologies" maintains a database of consumer nano-products http://www.nanotechproject.org/

Human Exposures

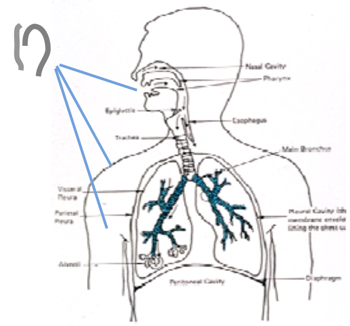
Four primary exposure routes are:
- inhalation
- dermal (skin) exposure
- ingestion
- injection / implantation

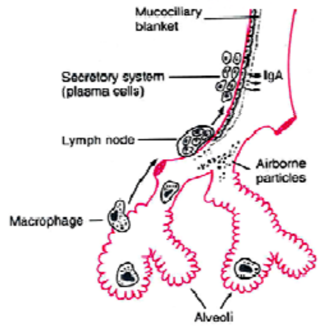
Some nanomaterials become easily airborn
- dry powders, mists from sonication, spraying

Particles < 5-10 um are respirable

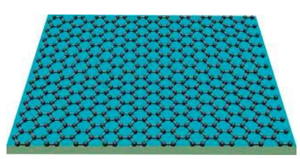
Nanomaterials may permeate the skin, or migrate up the olfactory nerve to the brain, but possibly in low doses

Nanoparticles can be ingested in food, beverage, or by swallowing after clearance from the lung





Exposure Example: Graphene



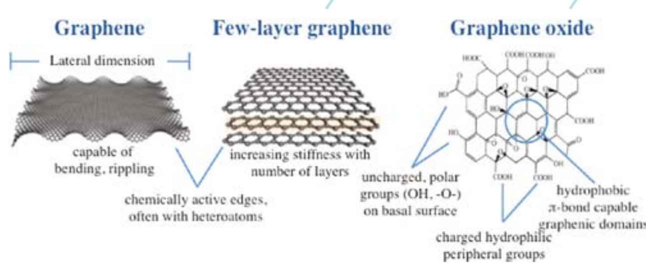
Graphene – the single-atom-thick sheet of sp2-hydribized carbon first isolated from graphite in 2004

Above: monolayer epitaxial graphene silicon substrate for nanoelectronics
→ likely not a significant exposure risk

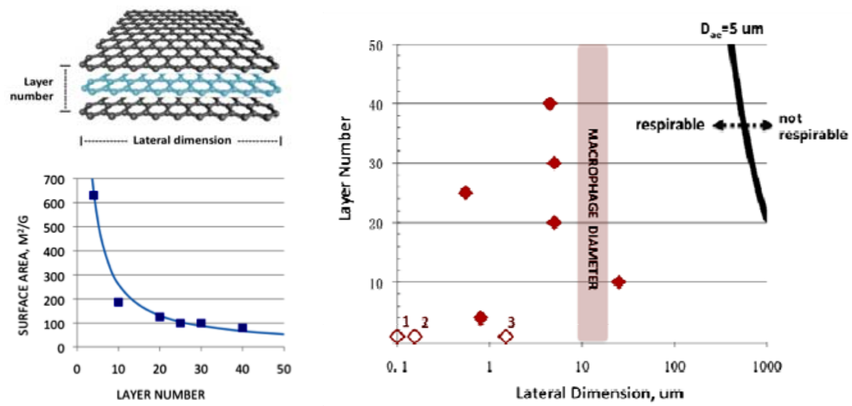
Related forms, however…..

Typically produced as bulk dry powder

Typically produced as aqueous suspension, which can be used in biomedicine or aerosolized

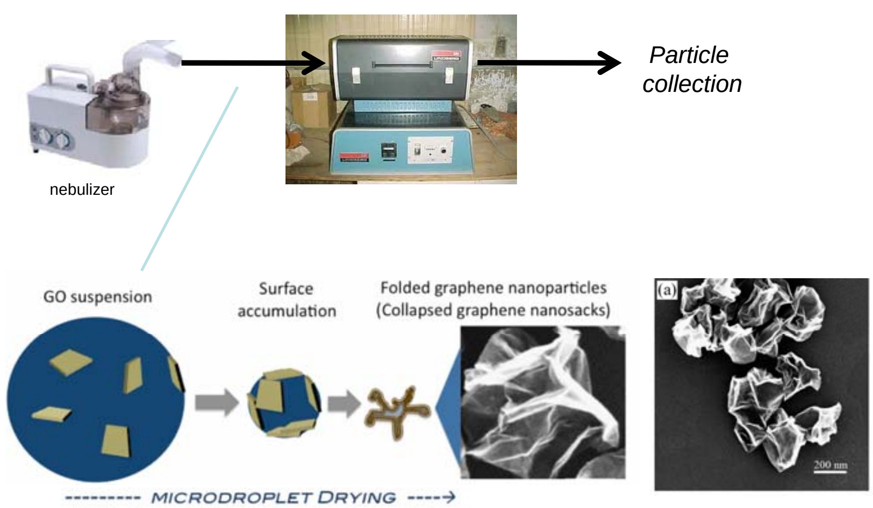


Many "Few-Layer-Graphene" Samples are Potentially Respirable



….and some are larger than macrophages and may not be cleared from the lung

Graphene Oxide Solutions May Be Aerosolized to form Respirable "Crumpled Graphene Nanoparticles"



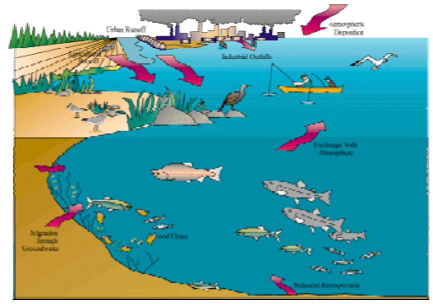
Environmental Impacts and Environmental Health

Exposure Scenarios

Occupational / consumer (inhalation, ingestion, skin contact)
→ of most immediate concern

Medical (injection for imaging, drug delivery…)
→ toxicity characterization already a major part of drug / therapy development

Environmental
→ emerging issue: are nanomaterials the pollutants of the future?



Some environmental issues

- What is the toxicity of high-volume nanoparticles to aquatic / terrestrial organisms, microbial communities ?
- Are nanoparticles bioavailable to organismal tissues? Do they bioaccumulate, biomagnify through trophic transfer?
- How/where are nanoparticles transported in the environment?
- Do nanoparticles persist in the environment? Do they transform?

Example of Environmental Transformation and Fate: NanoSilver

Jingyu Liu,
Ph.D. student,
Brown University

Synthesis

Sodium citrate
$NaBH_4$

$AgClO_4$

↓

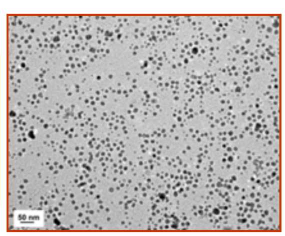
Washed by deionized water twice

↓

40 mg/L nAg colloid

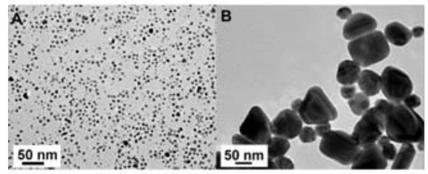
Two questions:

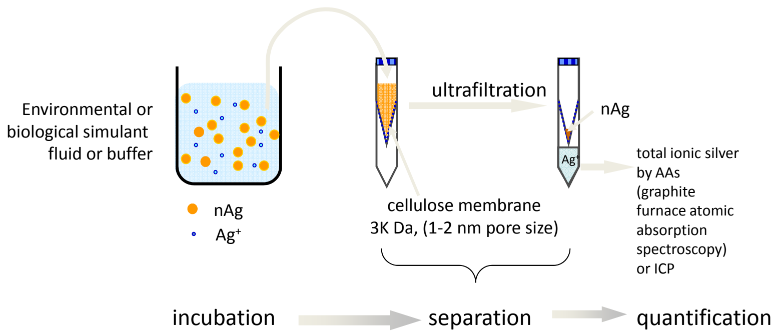
1. Will these noble metal nanoparticles be stable (persistent) in the environment ?
2. in suspension, Ag NPs usually co-exist with Ag^+ ions, which determine much of their biological / environmental activity. What determines this ion concentration ?



Citric-acid stabilized AgNPs
Average size: 5~8 nm

A general measurement method for ion-nanoparticle partitioning





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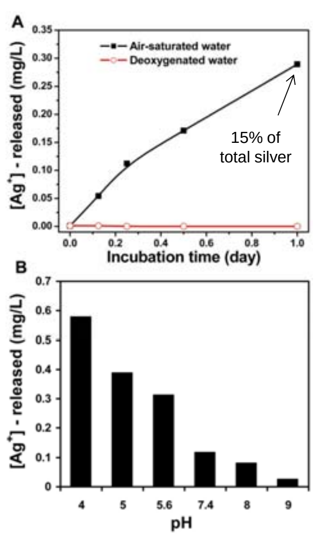
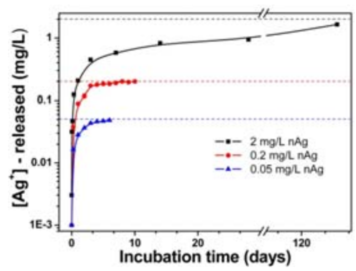
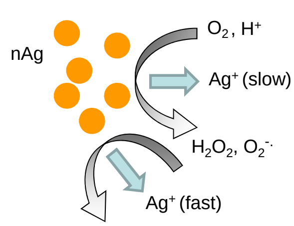
Results: ion-particle partitioning in nanosilver





nAg particles are not persistent in the presence of O_2 !

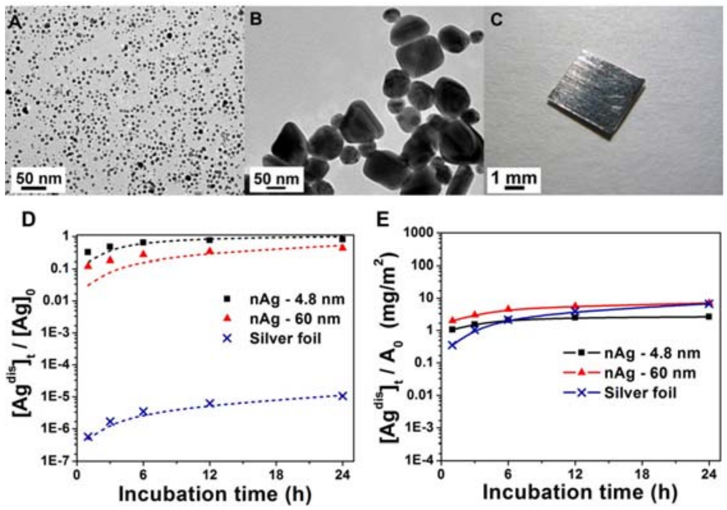


This reaction produces active peroxide intermediates

Is inhibited by natural organic matter

Leads to complete particle dissolution in aerobic environments

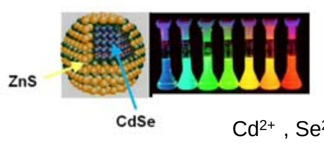
If nano-silver oxidatively dissolves, why doesn't bulk silver?



Answer: it can! (but slowly – about 1 nm/day)

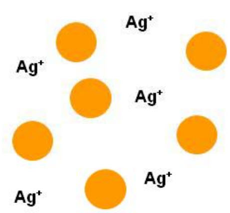
Leaching, or ion-particle partitioning,
Is a major theme in nanomaterial safety

Quantum dots

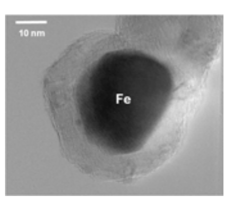


Cd^{2+} , Se^{2-} , Zn^{2+}

Antibacterial nanosilver



Carbon nanotubes

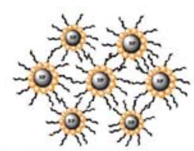


Fe^{2+}, Ni^{2+}, Y^{3+}, Co^{3+}….

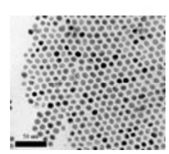
ZnO

Zn^{2+}

Ni

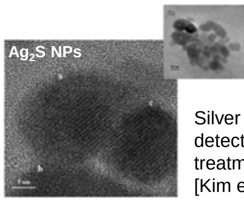


NiO



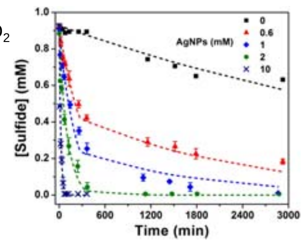
Ni^{2+}

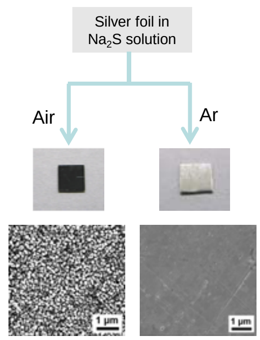
Nanosilver “corrodes” by dissolution – does it also “tarnish”?

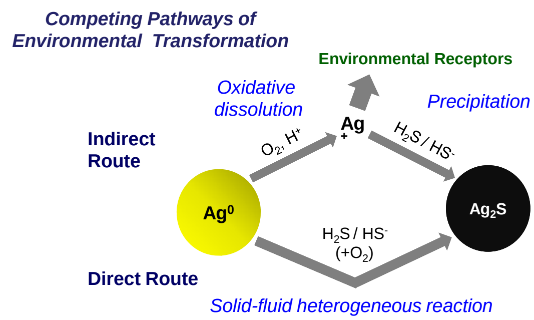


Silver sulfide nanoparticles detected in waste water treatment sludge [Kim et al., ES&T, 2010]

In the lab, nanosilver reacts with sulfide in the presence of O_2

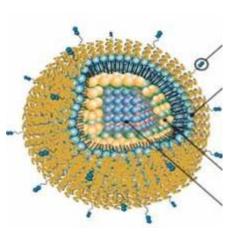


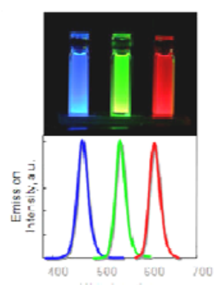




Nano-Enabled Consumer Products

Example: Quantum Dot Composites for Energy-Efficient Lighting





CdSe quantum dots absorb
short-wavelength light and emit longer wavelength light
-- thus they red-shift the LED spectrum
without the losses that simple filters would cause

Seth Coe-Sullivan, Sc.B. eng. ‘09
Chief Technical Officer, QDVision

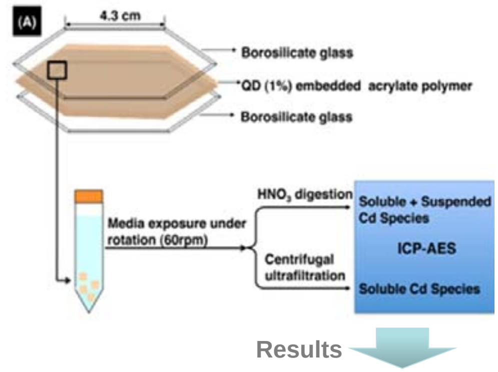
A “quantum dot optic”

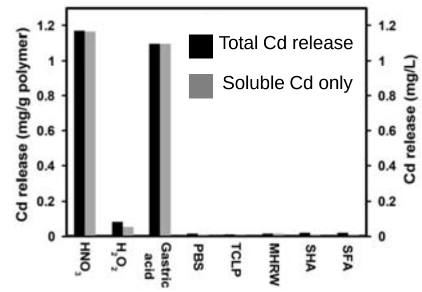
“Emotionally satisfying” LED lighting

Nano-enabled Products

Example: End-of-Life Behavior of the Quantum Dot Optic

- Do Cd, Se leach from the optic after disposal?
- Are QD nanoparticles released to the environment through degradation processes?



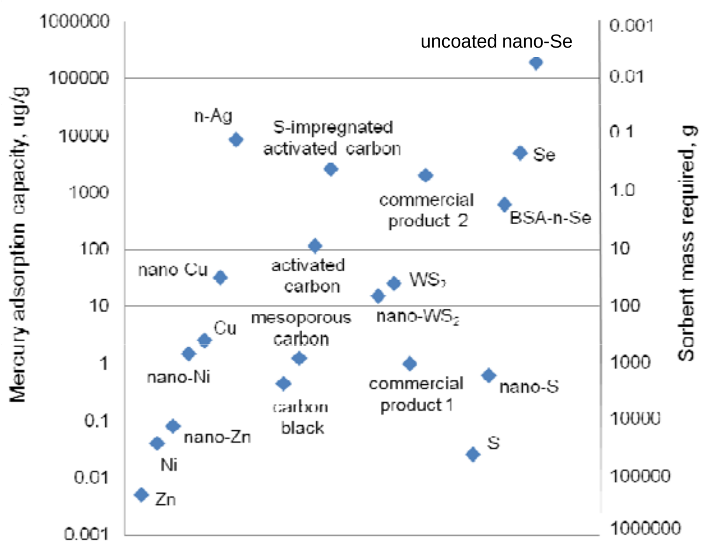


The QD optic releases small amounts of Cd and Se through water infiltration and quantum dot dissolution

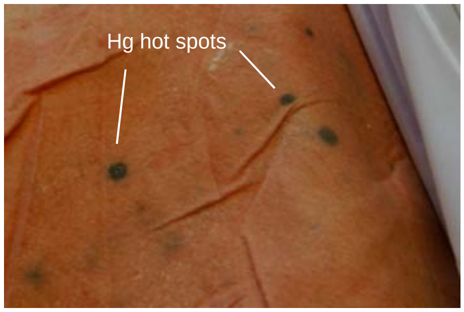
There is no evidence of nanoparticle release, or unique "nanospecific" risk

Example environmental *Application:* Nanomaterials for Hg vapor capture

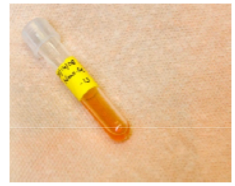
Some types of nano-selenium have ultrahigh activity for Hg vapor capture



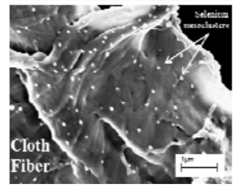
Nano-selenium formulations offer self-sensing and mercury detection



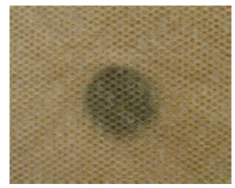
Colloidal form



nanoclusters
supported
on cellulose



controlled
demonstration
of indicator
function



Nano-sorbent has the advantage of optical reporting:

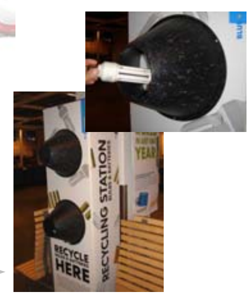
Self-sensing function - is the sorbent spent?

Mercury finder function - where was the spill / break?

Smart boxes, bags for safe recycling

Technologies for permanent Hg sequestration

The Nanostructured Sorbent as a Platform Technology



Retail drop-off boxes

Power plant flue gas capture

Cartridge-based air-cleaning for NASA spaceflights

Consumer spill and disposal kits

REUSE IN RHODE ISLAND
A State-Based Approach To Complex Exposures

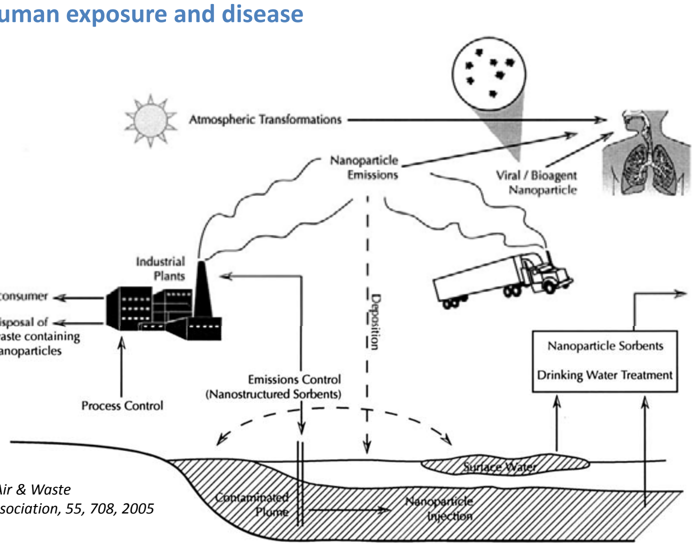
BROWN

Financial support from the US EPA Science to Achieve Results Program, the NSF NIRT program, and the NIEHS Superfund Research Program grant at Brown is gratefully acknowledged

The Laboratory for Environmental and Health Nanoscience

ENVIRONMENTAL AND HUMAN HEALTH IMPACTS OF NANOTECHNOLOGY

1. Environmental bioaccumulation and toxicity to aquatic organisms
2. Human exposure and disease



Biswas & Wu, J Air & Waste Management Association, 55, 708, 2005

1. ENVIRONMENTAL BIOACCUMULATION AND TOXICITY TO AQUATIC ORGANISMS

October 28, 2011: The Environmental Protection Agency issued a proposed $101 million cleanup plan for the Centredale Manor superfund site in North Providence.

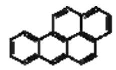
Dioxins
TCE, PCE
Metals (Pb, Cd, Cu, As)
SVOC s: PAHs
PCBs


Benzene


Toluene


Ethylbenzene


Pyrene


Benzo(a)pyrene

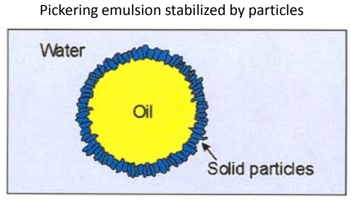
- **Carbon black nanoparticles and carbon nanotubes have sp^2-hydridized graphenic carbon surfaces**
- **High surface area for adsorption of PAHs by π-π bonding**

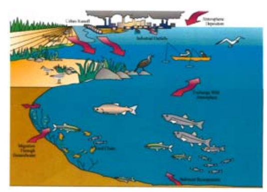
Delgado et al. J Mater Chem 18, 1417, 2008

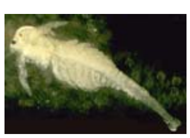
NANOPARTICLE-BASED DISPERSANTS FOR ENVIRONMENTAL REMEDIATION OF POLYCYCLIC AROMATIC HYDROCARBONS

Deepwater Horizon Disaster, 2010

Pickering emulsion stabilized by particles







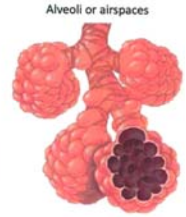
Bioaccumulation in simplified aquatic food chain

brine shrimp → killifish larvae → adult fish

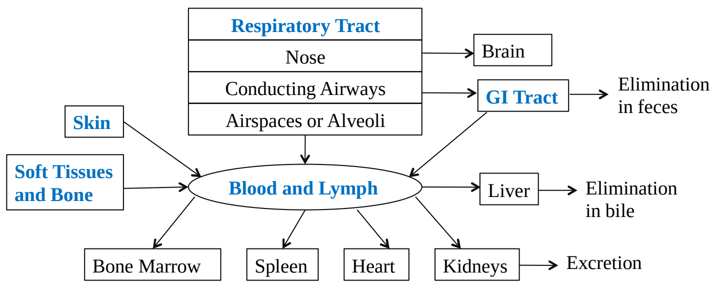
Hypothesis: Nanoparticle-based dispersants will stabilize oil-water emulsions, adsorb aromatic hydrocarbons, and decrease their toxicity and bioavailability.

2. INHALATION AND SYSTEMIC TRANSLOCATION OF NANOPARTICLES

Exposure → Dose → Response



Galya Orr, Pacific Northwest National Laboratory



Exposure, systemic translocation, and elimination

POTENTIAL CHRONIC TOXICITY OF NANOMATERIALS

NEL et al. SCIENCE 311: 622-627, 2006

TISSUE TARGET	DISEASE
Macrophages and inflammatory cells	granulomas chronic inflammation fibrosis or scarring
Lungs	cancer, mesothelioma
Blood vessels	stroke, heart attack
Immune system	autoimmune disease leukemia, lymphoma
Nervous system, brain	heart arrhythmia brain injury

Occupational Carcinogens

Agent	Industry	Target Site
Arsenic	Glass, metal, pesticide	Lung, Skin
Asbestos	Construction	Lung, Pleura, Larynx
Benzene	Chemical	Leukemia
Beryllium	Aerospace	Lung
Cadmium	Dyes, batteries	Lung, Prostate, Kidney
Chromium (VI)	Metal plating, welding	Lung, Nasal Sinus
Nickel	Metallurgy, alloys	Lung, Nasal Sinus
Crystalline silica	Mining, glass, pottery	Lung
Sulphuric acid mists	Metallurgy	Larynx
Benzo[a] pyrene	Coal gasification, paving and roofing	Lung

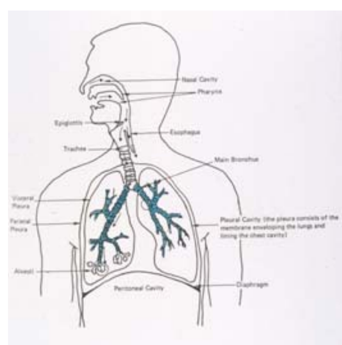
P. Boffetta, Epidemiology of environmental and occupational cancer, Oncogene 23: 6392-6403, 2004.

THE ASBESTOS-CARBON NANOTUBE ANALOGY

History of Asbestos-Related Diseases

Becklake, Am. Rev. Resp. Dis. 114:187-227,1976

Disease	Established Casual Association
Asbestosis	1930
Lung Cancer	1955
Mesothelioma	1965
Cancer of Larynx	2006
Nanodiseases	????

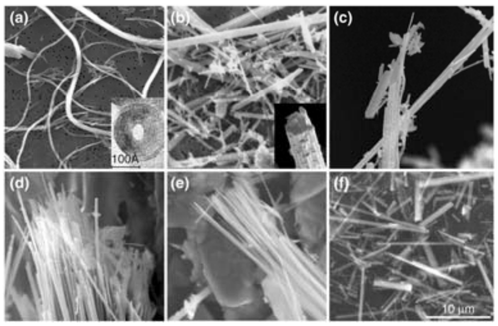


- The Potential Environmental Impact of Engineered Nanomaterials.
  Vicki L. Colvin, Nature Biotechnology, October, 2003
- Ethical and Scientific Issues of Nanotechnology in the Workplace
  Paul A. Schulte and Fabio Salamanca – Buentello, Environ Health Perspect, 2007
- Researchers Find Nanotubes May Pose Health Risks Similar to Asbestos
  The New York Times, May 21, 2008

The Asbestos-Carbon Nanotube Analogy

Asbestos Fibers

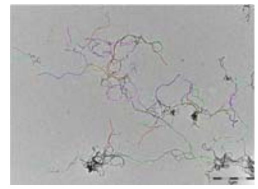
Chrysotile crocidolite anthophyllite

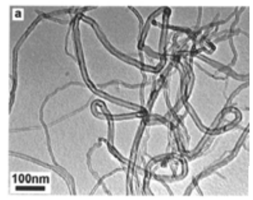


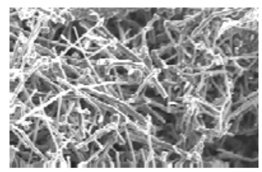
winchite-richterite tremolite amosite

U.S. Geological Survey

Carbon Nanotubes







Properties of Fibers Relevant for Biological Activity

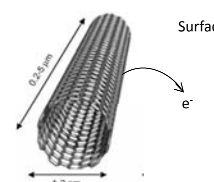
1. **Surface reactivity**
2. **Durability and biopersistence**
3. **Fibrous shape and dimensions**

Properties of Fibers Relevant for Biological Activity

1. Surface Reactivity of Asbestos Fibers and Carbon Nanotubes

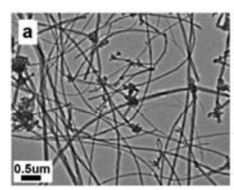
Crocidolite asbestos
$Na_2 Fe^{2+}{}_3 Fe^{3+}{}_2 (Si_8O_{22})(OH)_2$

Fenton chemistry:
$H_2O_2 \xrightarrow{Fe^{2+}} OH^{\bullet}$



Reilly *et al* (2007) JNM, 48: 1039-1042

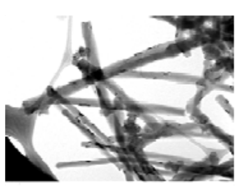
Surface e- donor:
$O_2 \rightarrow O^{\cdot -}_2$

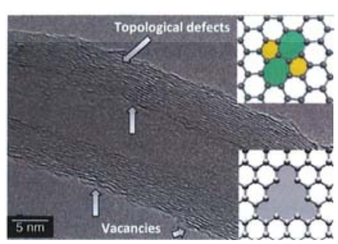


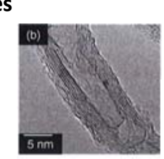
Carbon nanotubes

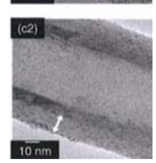
Surface Defects and Impurities in Carbon Nanotubes

Iron Catalyst Residues









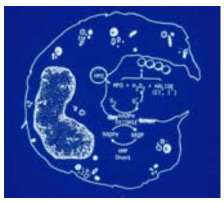
Properties of Fibers Relevant for Biological Activity

2. Biopersistence

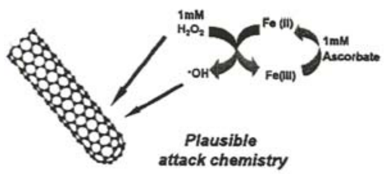
Fiber	T 1/2 in vivo (days)	Carcinogenicity
Crocidolite asbestos $Na_2 Fe^{2+}{}_3 Fe^{3+}{}_2 (Si_8O_{22})(OH)_2$	> 600	+
Wollastonite $CaSiO_3$	21	-
Fiberglass CaO: 38% SiO_2: 60%	77	-

Biopersistent mineral fibers are toxic and carcinogenic in rodents

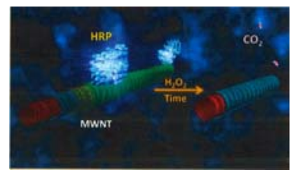
Bernstein et al., Inhalation Toxicol, 2005
Macdonald & Kane, Fund. Appl. Toxicol., 1997



Phagocytic Vacuole:
- Low pH (4.5)
- Endogenous ROS, Fe



Carboxylated Carbon Nanotubes are Oxidatively Degraded at Low pH
Liu et al. Carbon, 2010



Zhao et al. J. Phys. Chem. A, 115:9536, 2011

Enzymatic Degradation by Horseradish Peroxidase

Properties of Fibers Relevant for Biological Activity

3. Fibrous Shape and Dimensions

Long Fibers Induce Frustrated Phagocytosis and Impair Clearance

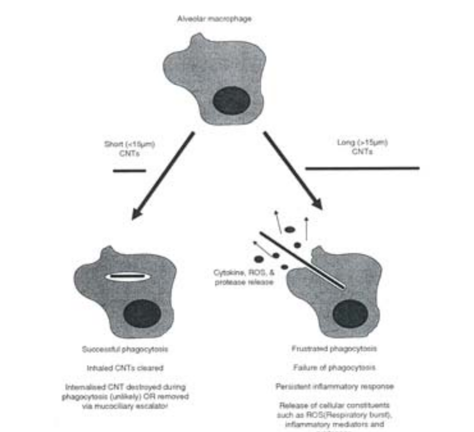
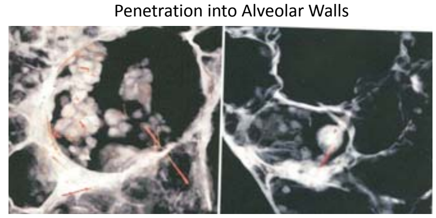


Figure 3. The importance of CNT length to their clearance by alveolar macrophages. Short CNTs (<15 μm) are easily cleared by macrophages, whereas longer CNTs (>15 μm) are not engulfed by macrophages, and frustrated phagocytosis ensues.

Incomplete or Frustrated Phagocytosis by Macrophages

Penetration into Alveolar Walls



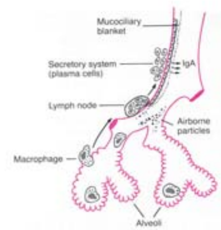
J. Brain, Harvard School of Public Health

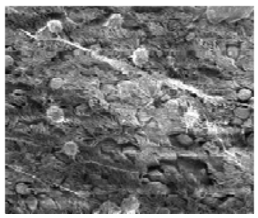
Johnston HJ, Hutchison GR, Christensen FM, Peters S, Hankin S, et al. "A Critical Review of the Biological Mechanisms Underlying the in Vivo and in Vitro Toxicity of Carbon Nanotubes: The Contribution of Physico-chemical Characteristics." Nanotoxicology June 4.2 (2010): 207-46.

Intratracheal Instillation of CNTs Causes Impaired Lung Clearance and Translocation to the Pleural Space

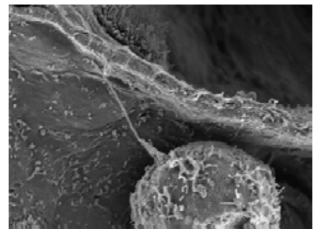
Lung Clearance Mechanisms

Daniele, Immune defenses of the lungs, 1988





Long carbon nanotubes on the mucociliary escalator after 7 days



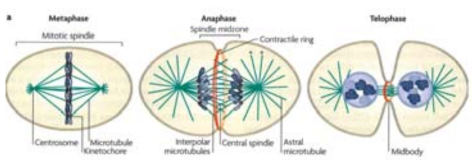
Frustrated phagocytosis of a carbon nanotube by an alveolar macrophage after 7 days

Penetration Into the Pleural Space

Robert Mercer, NIOSH SEM

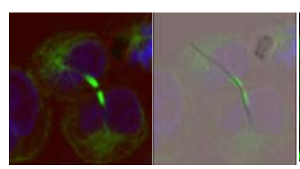
PROPERTIES OF FIBROUS NANOMATERIALS AND CARCINOGENICITY

Asbestos Fibers and Carbon Nanotubes Induce Micronuclei And Mitotic Abnormalities in Human Lung Epithelial Cells

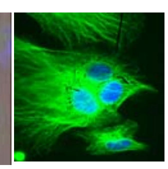


Glotzer, Nat. Rev. Mol. Cell Biol. 10:9, 2009

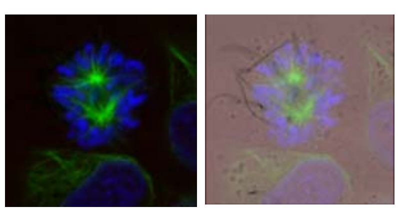
Microtubules-green fluorescence; nuclei and chromosomes-blue fluorescence



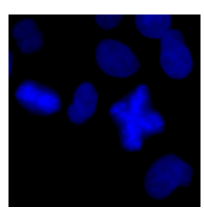
Carbon nanotube localized in midbody. Confocal microscopy- fluorescence and DIC.



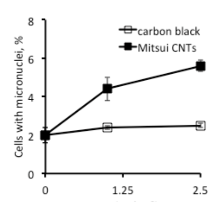
Carbon nanotubes induce multinucleated daughter cells.



Carbon nanotubes interfere with chromosomal segregation. Confocal microscopy- fluorescence and DIC.

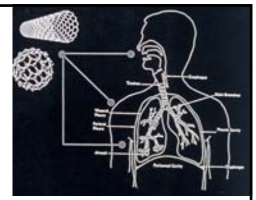


Asbestos fibers induce multipolar mitoses.



Lagging chromosomes produce micronuclei in daughter cells- 48 hours after exposure to CNTs.

Physicochemical Properties of Fibers Associated with Carcinogenicity



Asbestos fibers/ ? Carbon nanotubes + macrophages

Fiber geometry ↓

Frustrated phagocytosis

Redox activity ↙ ↘ Biopersistence

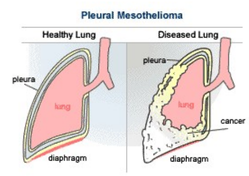
Macrophage recruitment and activation	Translocation to lung epithelial cells and pleura

growth factors
cytokines
oxidants ↓ ↓

Cell proliferation, persistent inflammation, DNA damage

↓ ↓

Lung cancer — Malignant mesothelioma



Unresolved questions:
- Do carbon nanotubes translocate to the pleura following inhalation?
- Is their surface activity modified in vivo?
- Does acute toxicity predict chronic disease endpoints?

Institute for **Molecular and Nanoscale Innovation** — BROWN

Summary

1. Nanotechnology has significant promise for energy generation, electronics, medicine, aerospace, defense, and environmental remediation.
2. Environmental toxicity and adverse human health effects are potential implications of nanotechnology.
3. The physical and chemical properties of nanomaterials responsible for cell toxicity are related to geometry, length, surface redox reactivity and biopersistence.
4. Commercial carbon nanotubes induce DNA damage and mitotic abnormalities in lung epithelial cells and mesothelial cells similar to asbestos fibers.
5. Engineers will be able to design less toxic, biocompatible and biodegradable nanoparticles for commercial applications that will minimize adverse environmental and health impacts.

Collaboration Between Kane and Hurt Labs:

Annette von dem Busshe, Ph.D.
Charlie Vaslet, Ph.D.
Norma Messier
Paulette Ferland
Ashish Jachak, Ph.D.
April Rodd

Indrek Kulaots, Ph.D.
Megan Creighton
Xinyuan Liu
Yang Qui
Jingyu Liu
Fei Guo

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Gulf of Mexico Research Institute, Brown
Subcontract from Tulane University
DoED GAANN Grant