NIEHS National Institute of Environmental Health Sciences

RISK*e*Learning

Nanotechnology – Applications and Implications for Superfund

January 18, 2007
Session 1:
"Introduction to Nanotechnology"
Dr. Nora Savage, EPA ORD NCER
Dr. Nigel Walker, NIEHS NTP

Organizing Committee:

SBRP/NIEHS	EPA		MDB
William Suk	Michael Gill	Nora Savage	Maureen Avakian
Heather Henry	Jayne Michaud	Barbara Walton	Larry Whitson
Claudia Thompson	Warren Layne	Randall Wentsel	Larry Reed
Beth Anderson	Marian Olsen	Mitch Lasat	
Kathy Ahlmark	Charles Maurice	Martha Otto	

EPA & NANOTECHNOLOGY:

STRATEGY, RESPONSIBILITY AND ACTIVITY

January 18, 2007

Nora Savage, PhD

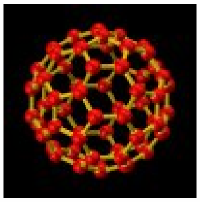
US EPA,
Office of Research & Development
National Center for Environmental Research
Environmental Engineering Research Division

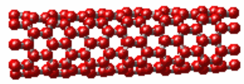
EPA United States Environmental Protection Agency

OUTLINE

- Nanotechnology
- NNI Structure and Activities
- EPA Interest in Nano
- Superfund & Nano
- ORD Activities
- ORD Sponsored Research
- Path Forward

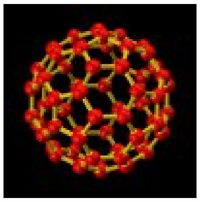
Definition of Nanotechnology?

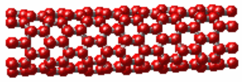




- The ability to extract large sums of money from a decreasing federal research budget?

Definition of Nanotechnology?

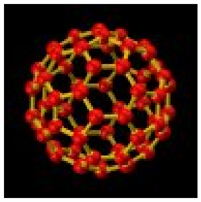


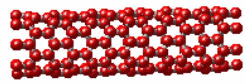


- The development of novel properties for any business with "nano" prefix?

United States Environmental Protection Agency

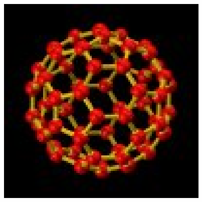
Definition of Nanotechnology?

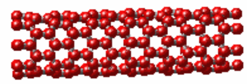




- The capacity to manipulate at the nano level to multiply exponentially the number of nano meetings?

NNI Definition of Nanotechnology





- Understanding and control of matter at dimensions of roughly 1 to 100 nanometers;
- Unique phenomena enable novel application
- Imaging, measuring, modeling, and manipulating matter at this length scale

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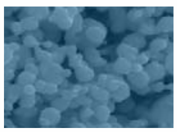
Unique Properties of Nanoscale Materials

- Chemical reactivity of nanoscale materials greatly different from more macroscopic form, e.g., gold
- Vastly increased surface area per unit mass, e.g., upwards of 100 m^2 per gram
- Quantum effects resulting in unique mechanical, electronic, photonic, and magnetic properties
- New chemical forms of common chemical elements, e.g., fullerenes, nanotubes of carbon, titanium oxide, zinc oxide, other layered compounds

Nanoscale Materials

Engineered	Incidental	Natural
• Carbon-based NTs, Fullerenes • Metal Oxides • Quantum Dots • Nanotubes • Nanowires • Dendrimers 	Particles from: • Combustion • Industrial Processes • Vehicles • Construction 	Particles from: • Plants, Trees • Oceans, other water bodies • Erosion • Dust 

Nano-Products on the Market Now

EPA United States Environmental Protection Agency

- Cosmetics – face creams, sunscreens, make-up
- Textiles – clothing, furniture, carpeting
- Sports Equipment – balls, bats, rackets, bicycles
- Electronics – computers, televisions
- Appliances – washing machines, refrigerators
- Cleaning Agents – household, remediation

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Nano-Products on the Market Now

Display Screens
Motorola (NTs)

Automobiles
(BASF's Mincor® Nanocomposite)

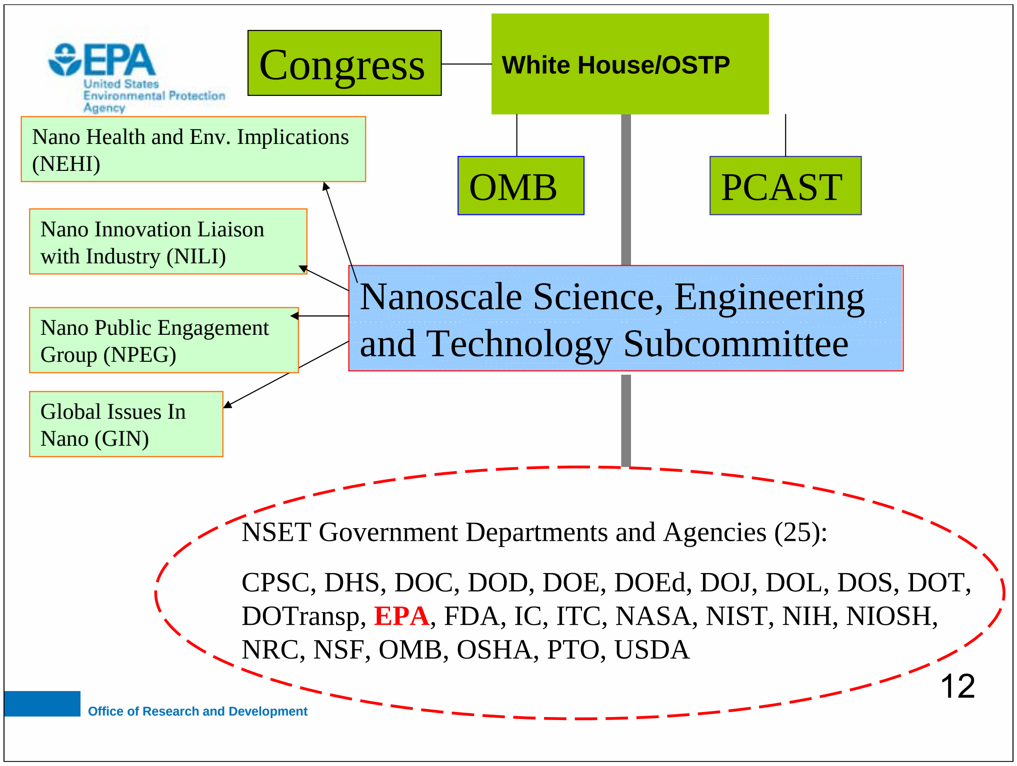
Nano Silver Wash Washing Machine
Samsung (400 billion silver ions)

Tennis Rackets
Wilson (C fibers)

National Nanotechnology Initiative

EPA is a member of the subcommittee - Nanoscale Science, Engineering and Technology (NSET)

- **Federal agencies and departments that participate in NNI**
- **Established in 2001**
- **Responsible for coordinating federal government's nanoscale research and development programs**
- **National Nanotechnology Coordinating Office (NNCO) – secretariat, point of contact**



PCAST designated as President's National Nanotechnology Advisory Panel

NEHI – Nanotechnology Environmental and Health Implications

www.nano.gov for more information

DHS- Dept. of Homeland Security

IC – Intelligence Community

ITIC – Intelligence Technology Innovation Center

DOS – Dept. of State

NNI Environment, Health and Safety Research

NSF	Basic research: environmental effects of nanoparticles; nanoparticles in air pollution; water purification; nanoscale processes in the environment
EPA	Toxicology of manufactured nanomaterials; Fate, transport, & transformation; Human exposure and bioavailability
DoD	Physicochemical characteristics & toxicological properties of nanomaterials computational model that will predict toxic, salutary and biocompatible effects based on nanostructured features
NTP	Potential toxicity of nanomaterials, titanium dioxide, several types of quantum dots, & fullerenes
DoE	Transport & transformation of nanoparticles in the environment, exposure & risk analysis; Health effects
NIH	Nanomaterials in the body, cell cultures, and laboratory use for diagnostic and research tools
NIST	Developing measurement tools, tests, and analytical methods

Federal NNI Research: Environment, Health and Safety: 07 Request* (Million)

• NNI total	$1,054.0
• NNI EHS research	44.1
–NSF	25.7
–EPA	8.0
–NIH	4.6
–NIOSH	3.0
–DOC (NIST)	1.8
–DOD	1.0

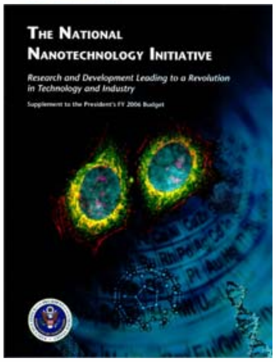
*Includes only efforts whose primary purpose is to understand potential risks to health and the environment.

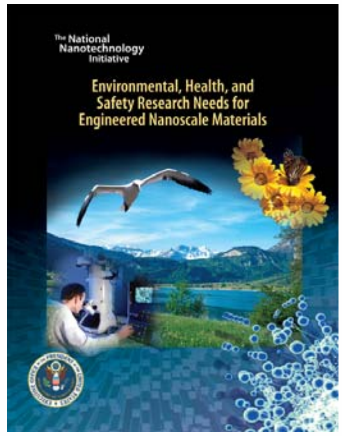
NNI Website

www.nano.gov

NNI goals:

- Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology;
- Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit;
- Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; and,
- Support responsible development of nanotechnology





Available on web at:

http://www.nano.gov

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EPA's Interest in Nanotechnology

- **Promise for environmental protection**
  - Cleaning up *past* environmental problems
  - Improving *present* processes
  - Preventing *future* environmental problems
- **Potential harmful effects to human health or the environment**
- **Regulatory responsibilities**
- **Consideration of environmental benefits and impacts <u>from the beginning</u>, as new technologies develop**

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Environmental Challenges & Opportunities

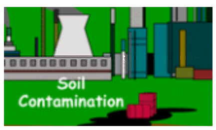
- Potential toxicity
- Potential exposure
- Fate, transport, transformation
- Bioavailability, bioaccumulation
- Critical metric: particle size/number, morphology, surface area, functionalization

- Remediation
- Monitoring/detection
- Environmentally benign processes/P2
- Treatment
- multi-functional devices
- Lab-on-a-Chip
- Reduced material, energy and costs

Superfund Nano Opportunities

- Sub-surface remediation
- Ground water remediation & protection
- Real-time monitoring and detection

Macalloy Corp. Site, North Charleston, SC, 1000th Superfund site completed



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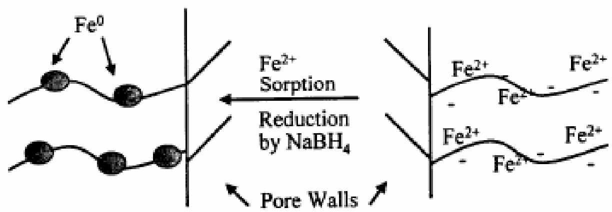
Superfund Nano Opportunities: Membrane-Based Nanostructures

Immobilization



Nanoparticles immobilized in membrane for treatment of hazardous organics in water. Use may lead to miniaturization of dechlorination reactor systems.

Dibakar Bhattacharyya, University of Kentucky

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EPA STAR nanotechnology research on treatment/remediation using membrane or polymer-based nanostructures. Bhattacharyya (Membrane-Based Nanostructured Metals for Reductive Degradation of Hazardous Organics (Chlorinated Ethenes and Aromatics) at Room Temperature) Diallo (Dendridic Nanoscale Chelating Agents: Synthesis, Characterization, Molecular Modeling and Environmental Applications) . Chen (Nanoscale Biopolymers with Tunable Properties for Improved Decontamination and Recycling of Heavy metals).

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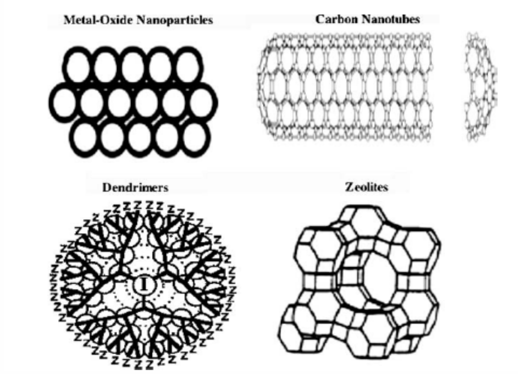
Superfund Nano Opportunities: Organic Pollutant Reduction



Treatment

Reductive dechlorination of organic pollutants in water or soil using nanosize FeS clusters immobilized in dendrimer nanostructures
Mamadou Diallo, Howard University

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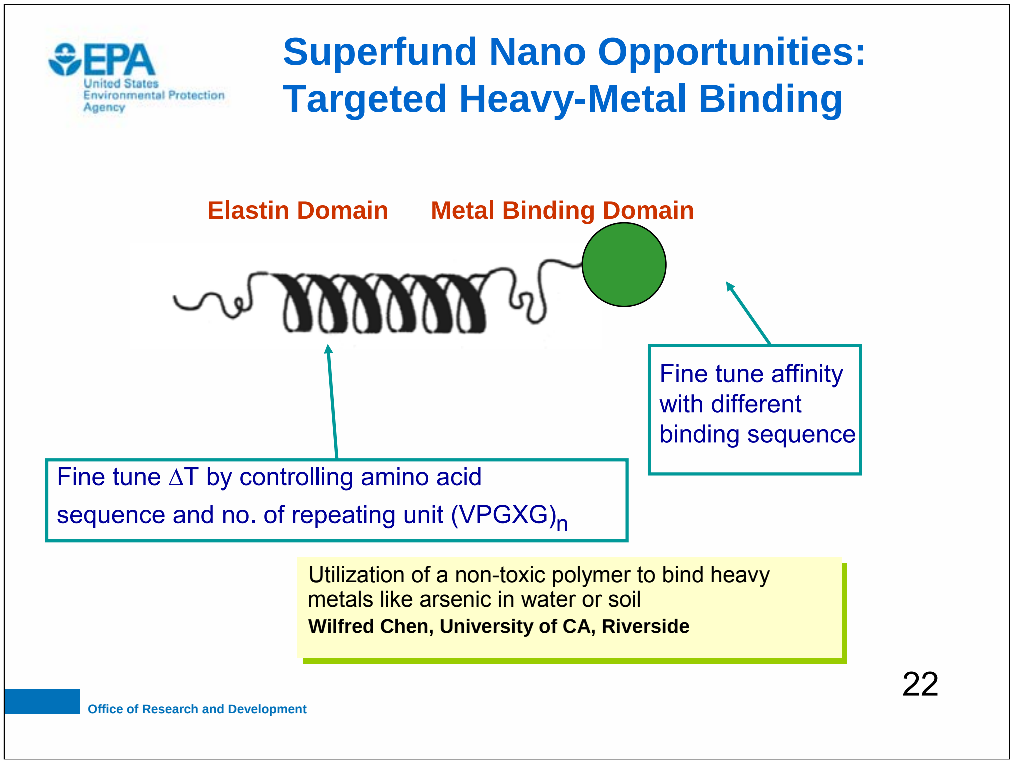
EPA STAR nanotechnology research on treatment/remediation using membrane or polymer-based nanostructures. Bhattacharyya (Membrane-Based Nanostructured Metals for Reductive Degradation of Hazardous Organics (Chlorinated Ethenes and Aromatics) at Room Temperature) Diallo (Dendridic Nanoscale Chelating Agents: Synthesis, Characterization, Molecular Modeling and Environmental Applications) . Chen (Nanoscale Biopolymers with Tunable Properties for Improved Decontamination and Recycling of Heavy metals).



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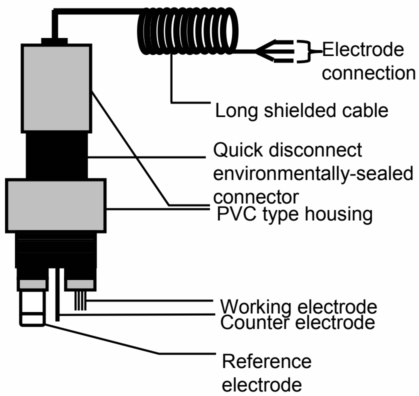
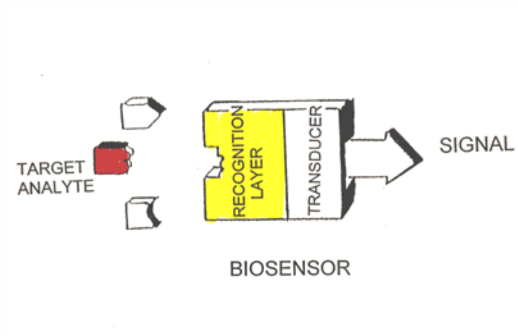
EPA United States Environmental Protection Agency

Superfund Nano Opportunities: Monitoring and Detection





Remote electrochemical and bio-sensors

J. Wang, Arizona State University

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Superfund Nano Challenges

- Fate
- Reactivity
- Transport & Mobility
- Organism effects
- Ecological effects
- Compound Interactions
- Biopersistence
- Bioavailability
- Biotransformation

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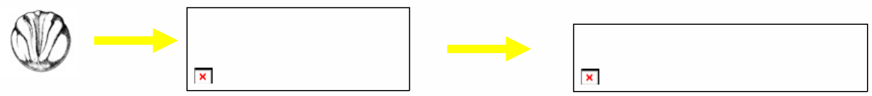
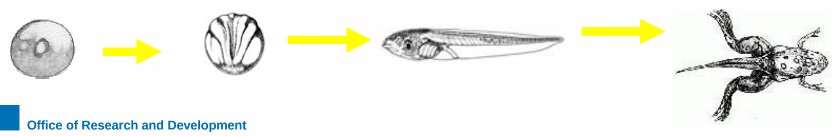
Superfund Nano Challenges: Organism Effects

Acute:
96-hour
Endpoints: growth, deformation, survival

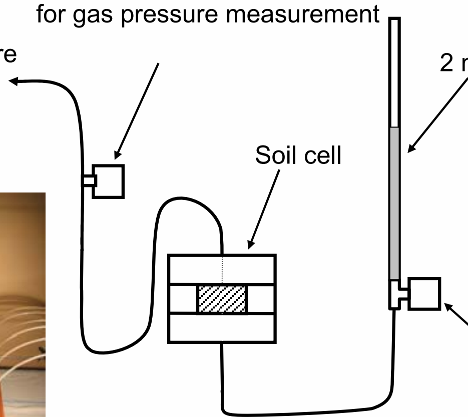
Acute and developmental toxicity, metal oxide nps
C. Theodorakis, Southern Illinois University



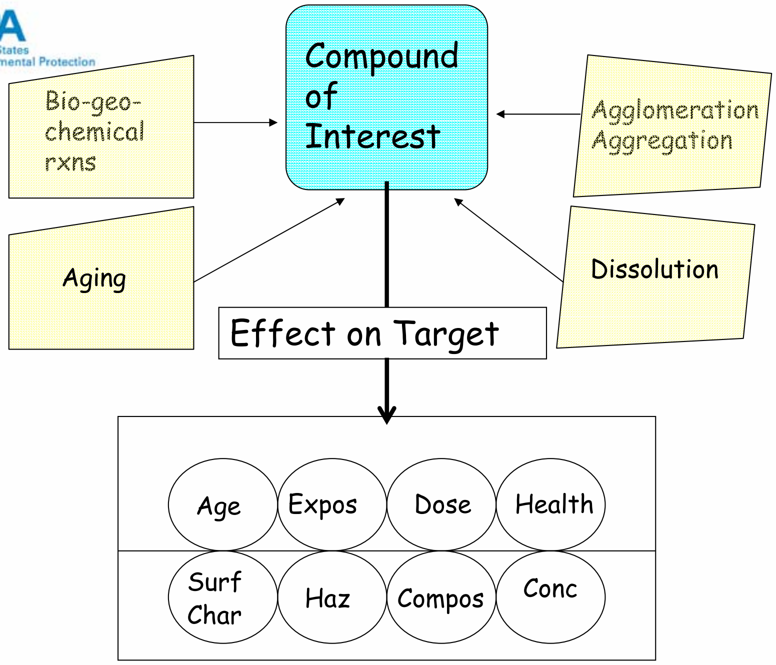
Chronic:
70 days
Endpoints: % hatch, growth, malformation, metamorphosis, survival



Superfund Nano Challenges: Fate and Transport



Vadose zone accumulation and release
T. Kibbey, University of Oklahoma


Compound of Interest
Bio-geo-chemical rxns
Agglomeration Aggregation
Aging
Dissolution
Effect on Target
Age
Expos
Dose
Health
Surf Char
Haz
Compos
Conc

Extramural Research at EPA

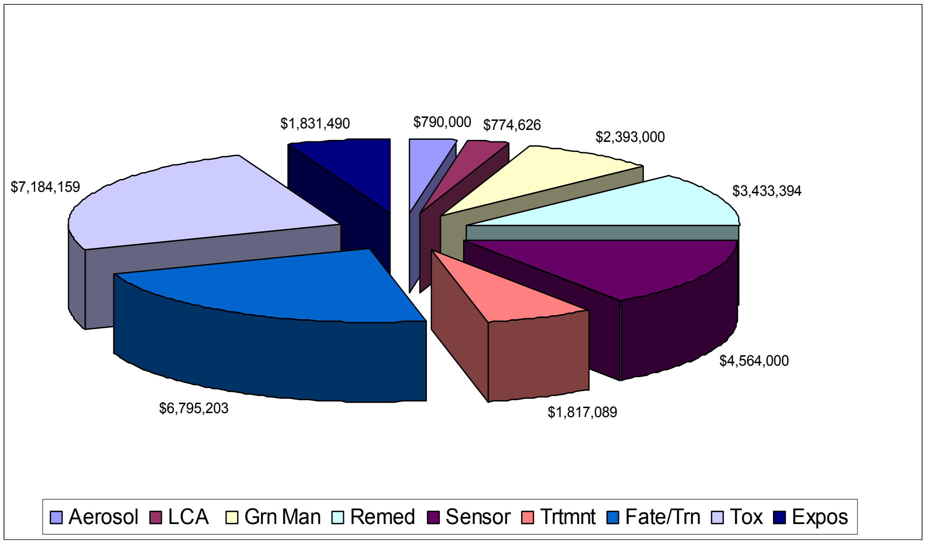
Applications address existing environmental problems, or prevent future problems

(Approx. $15.6 M to date)

Implications address the interactions of nanomaterials with the environment, and any possible risks that may be posed by nanotechnology

(Approx. $17.6 million to date, excluding ultrafine)

STAR Nano Grants



2005 STAR Solicitation

Environmental and Human Health Effects of Engineered Nanomaterials

- Joint with National Science Foundation (NSF), National Institute for Occupational Safety and Health (NIOSH), National Institute of Environmental Health Sciences (NIEHS)
- Open: December 20,2005 – February 22, 2006
- 21 Awards totaling $7.3 million (with other agencies 29 awards totaling $10.3 million)

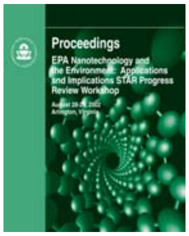
United States Environmental Protection Agency

2006 STAR Solicitation

Environmental and Human Health Effects of Nanomaterials

– Joint with National Institute of Environmental Health Sciences (NIEHS), and National Institute for Occupational Safety and Health (NIOSH)
– "Manufactured Nanomaterials: Physico-chemical Principles of Biocompatibility and Toxicity (R01): through NIEHS"
– ~ $7 million available for $0.5 million/yr, 4-yr awards
– Opens September 29, 2006 closes January 12, 2007

STAR Grantees - Meeting Proceedings



http://www.epa.gov/ncer/nano

Path Forward

- EPA Research Strategy
- EPA stewardship program
- International activities

Nanotechnology Research Strategy

In fiscal years 2007 and 2008, EPA will focus on the following high priority areas:

- Environmental fate, transport, transformation
- Exposure
- Monitoring and detection methods
- Effects assessment methods consistent with and derived via exposure information.

Nanotechnology Research Program

- EPA nanotechnology budget request for FY 07 is $8.6 Million for STAR and in-house research.
- $3 million of increase is for new research on nanotechnology in EPA's laboratories

Nanotechnology Research Strategy

Specific activities:

- Identifying, adapting, and, where necessary, developing methods and techniques to measure nanomaterials from sources and in the environment
- Enhancing the understanding of the physical, chemical, geochemical reactions nanomaterials undergo and the resulting transformations in air, soil and water
- Characterizing persistence and effects of nanomaterials through their life cycle in the environment
- Providing the capability to predict significant exposure pathway scenarios
- Providing data for use in human health and ecological toxicity studies
- Providing data for the development of the most relevant testing methods\protocols to determine toxicity of nanomaterials

International RFA Activities

European Commission

- Joint RFA to be released in 2007, with NIEHS, NSF & NIOSH
- Collaborations on research strategies

National University of Singapore

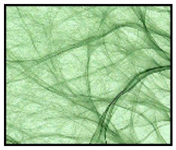
- Joint RFA to be released in 2007
- Collaborations on nano sensor technologies

EPA is also working with with the United Nations on research strategies and has recently signed MOUs with China, and EC to cooperate in science and technology areas, including nanotechnology.

Coming Soon: EPA's New Nano Web Page

NOW……..

Nanotechnology Home



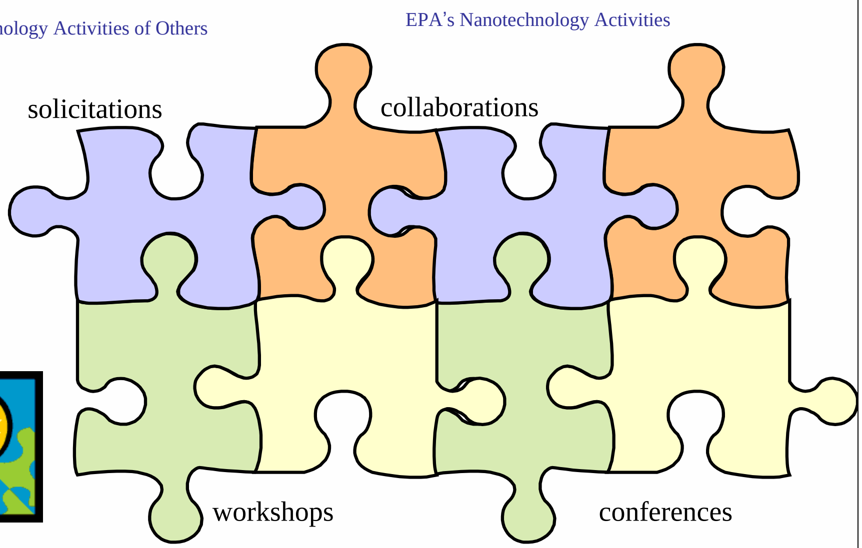
Nanotechnology has both applications and implications for the environment. EPA is supporting research in this technology while evaluating its regulatory responsibility to protect the environment and human health. This site highlights EPA's research in nanotechnology and provides useful information on related research at EPA and in other organizations.

- Nanotechnology
- Factsheet
- Solicitations
- Newsroom
- Research Projects
- Publications & Proceedings

www.epa.gov/ncer/nano

Coming Soon EPA-wide Website!!

SAFE NANOTECHNOLOGY DEVELOPMENT

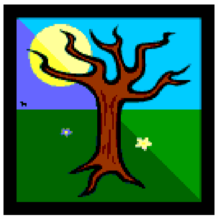


Nanotechnology – Environmental Goals

- enable a sustainable future

&

- usher in a vibrant spring



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Nanotechnology and toxicology: an overview

Nigel Walker Ph.D.

SBRP Webinar

January 18th 2007

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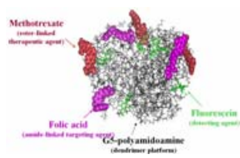
U.S. Department of Health and Human Services
National Institutes of Health
National Institute of Environmental Health Services

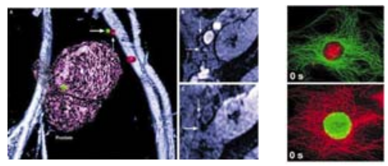
NIEHS
National Institute of Environmental Health Sciences

Desirable Applications of Nanotechnology

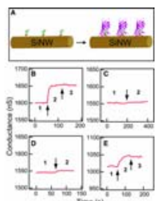
"Smart" therapeutics



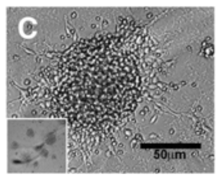
Targetted molecular imaging agents



Biological sensors/ diagnostic tools



Tissue engineering



Nano-enabled consumer products

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NIEHS National Institute of Environmental Health Sciences

Breadth of applications

- Nanoscale materials/Nanostructured materials
  - Purposefully engineered E.g fullerenes, dendrimers titanium dioxide, carbon nanotubes, quantum dots etc
- Nanointermediates
  - Intermediate products - neither raw materials nor goods that represent final consumption, that either incorporate nanoscale materials
- Nano-enabled products
  - Finished goods that incorporate nanomaterials or nanointermediates.
- Nanotools
  - Technical instruments and software used to visualize, manipulate, and model matter at the nanoscale.

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engineers

NIEHS
National Institute of
Environmental Health Sciences

What is "Nanotechnology"

- A term referring to a wide range of technologies that measure, manipulate, or incorporate materials and/or features with at least one dimension between approximately …
  - **1 and 100 nanometers (nm).**
- Such applications exploit the…
  - **properties, distinct from bulk/macroscopic systems**, of nanoscale component

ASTM E2456-06

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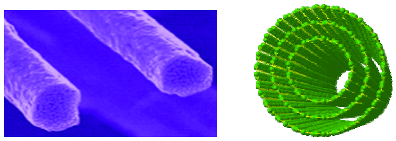
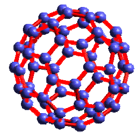
Diversity across classes of nanoscale materials

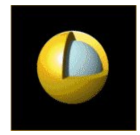
Single and multi walled nanotubes



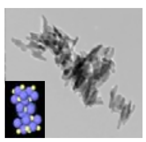
Fullerenes



Nanoshells

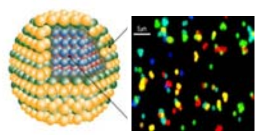


Metal oxides

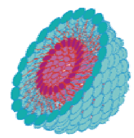


Dendrimers

Quantum dots



Nanosomes



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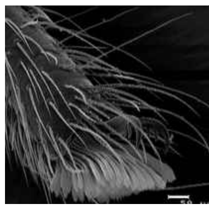
Responsible development of nanotechnology

"With Great Power, Comes Great Responsibility"

Uncle Ben *to Peter Parker in "Spider-Man"*



Nanoscale fibres on spider feet

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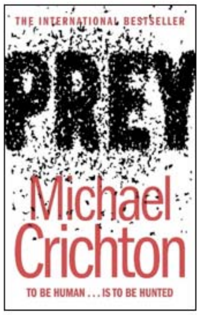
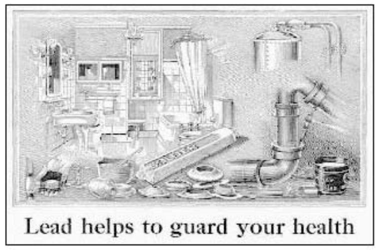
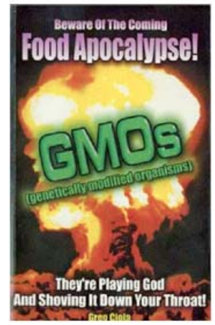
For Science, Nanotech Poses Big Unknowns

By Rick Weiss
Washington Post Staff Writer

Nanotechnology, the hot young science of making invisibly tiny machines and materials, is stirring people's blood vessels to treat diseases. Billions of dollars are being pumped into the field, and products with science-fiction-like properties have already begun to hit the market.







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Worth1000.com
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Cross cutting scientific challenges

- Fundamentals of interactions of nanoscale materials with biological systems
  - Physical, chemical or other interactions
  - How these are determined by the physical and chemical properties of nanomaterials
- Biocompatibility and toxicity
  - How these are determined by the physical and chemical properties of nanomaterials
- If we understand these then we can…
  - Manipulate
    - ..to engineer new applications based on desirable properties
    - ..to avoid nanomaterials with undesirable health effects
  - Evaluate
    - Impact on human health of exposures

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Technical and Scientific Challenges for nanotech

- What constitutes "nano"
  - Manufactured versus natural
- What are the critical determinants of toxicity?
- Are traditional toxicology models appropriate?
- How do we measure relevant doses and exposures?

Key Issues

Does what we've learned so far in toxicology apply to nanomaterials?

What makes "nano" different?

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Experimental Strategies

- Several workshops/reports with common issues recommendations
  - NTP Nanotoxicology workshop-Florida-Nov 2004
  - ILSI-RSI report (Oberdorster et al 2005, Particle Fibre Toxicol 2:8)
- Current tox models able to detect manifestations of novel mechanisms of action
  - Use of both in vivo and in vitro approaches
  - In vivo approaches needed for validation of in vitro effects
- Comprehensive physical/chemical characterizations
  - Development of appropriate dose metrics
  - Allows for informed interpretation, replication and extrapolation
- Need for multidisciplinary approach

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Risk is function of both the hazard and the exposure

- Exposure assessment
- Hazard identification
- Hazard characterisation
- Dose-response

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Areas of emphasis for NIEHS and NTP

- Exposure and dose metrics
  - How do we measure exposure?
- Internal dose-Pharmacokinetics in biological systems
  - What physiochemical properties determine the absorption, distribution and elimination of nanomaterials?
- Early biological effects and altered structure function
  - What physiochemical properties determine biocompatibility?
- Adverse effects
  - What are the critical determinants of toxicity for those that are toxic?

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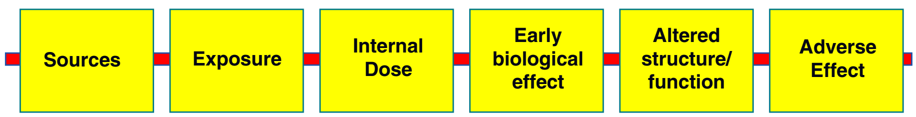

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Considerations in classifying nanomaterials

Primary Size	Shape	Surface	Composition	Structure
Nanoscale (1-100nm)	Spheroid	Neutral	Homogeneous	Monodispersed
Low nano (1-10)	Fibrous	Anionic	Heterogeneous	Aggregated
Mid nano (10-30)	Tubular	Cationic	Structured	Nanostructured
High nano (30-100)	Amorphous	Hydrophobic		
Sub-micron (100-1000nm)		Amphiphilic		
		ŅTargettedÓ		

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Physicochemical Characterization needs

- Bulk material and/or in dry vehicles
  - Identity and Composition
  - Purity
  - Reporting of synthesis byproducts
    - >0.1% mass
  - Identification of synthesis byproducts
    - >1% mass
  - Stability
  - Primary particle size and shape
  - Surface roughness
  - Crystal form (if applicable)
  - Surface area
  - Chamber particle size distribution
    - for inhalation studies

- Wet vehicles
  - Confirmation of concentration
  - Purity of vehicle
  - Homogeneity of formulation
  - Stability over course of study
  - Primary particle size and shape
  - Size distribution
    - % mass
    - % particle number
  - Surface chemistry
  - Surface charge

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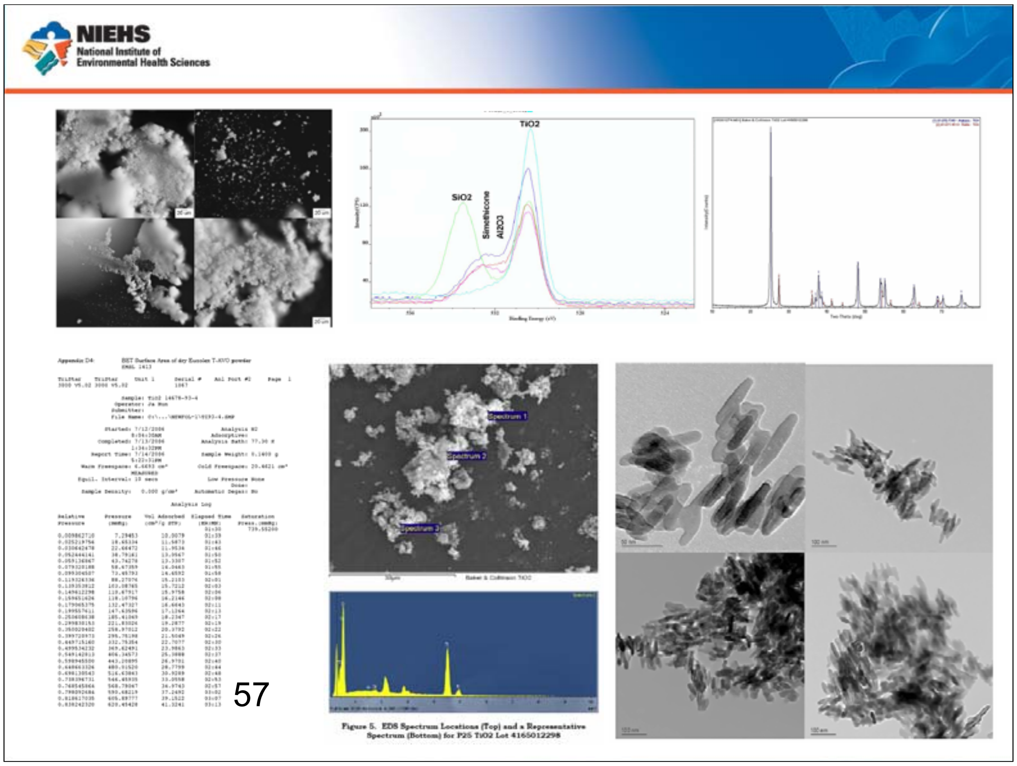
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SiO2
Simethicone
Al2O3
TiO2
Spectrum 1
Spectrum 2
Spectrum 3
Figure 5. EDS Spectrum Locations (Top) and a Representative Spectrum (Bottom) for P25 TiO2 Lot 4165012298
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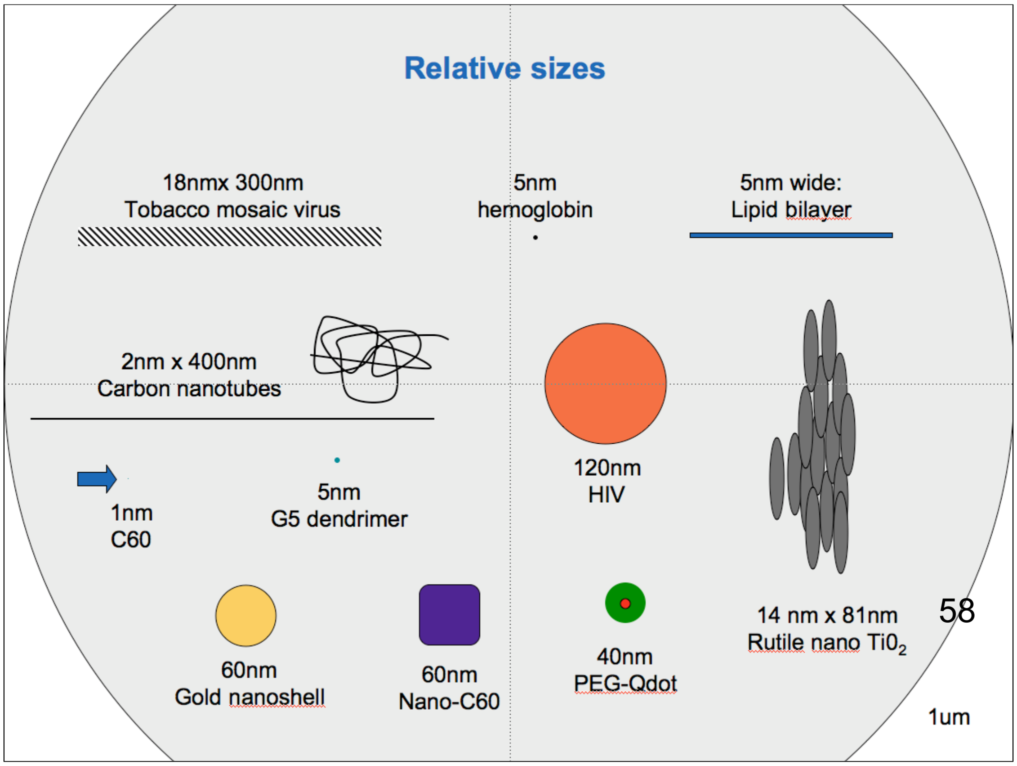
Relative sizes
18nmx 300nm
Tobacco mosaic virus
5nm
hemoglobin
5nm wide:
Lipid bilayer
2nm x 400nm
Carbon nanotubes
120nm
HIV
1nm
C60
5nm
G5 dendrimer
60nm
Gold nanoshell
60nm
Nano-C60
40nm
PEG-Qdot
14 nm x 81nm
Rutile nano Ti0$_2$
58
1um

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Variation in pulmonary deposition depending on size

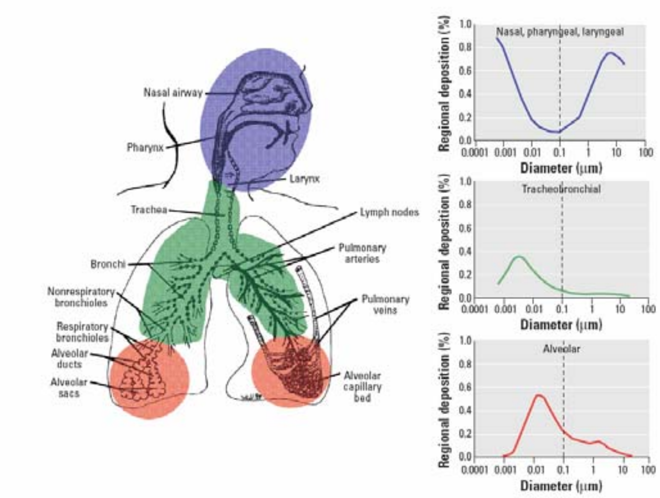

Figure 8. Predicted fractional deposition of inhaled particles in the nasopharyngeal, tracheobronchial, and alveolar region of the human respiratory tract during nose breathing. Based on data from the International Commission on Radiological Protection (1994). Drawing courtesy of J. Harkema.

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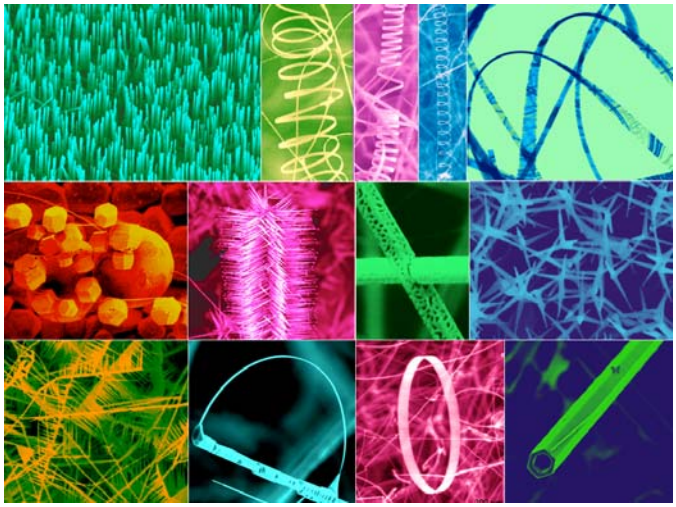
Shape affects surface properties



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Wang 2004, Materials Today

For some materials surface area may be a better metric

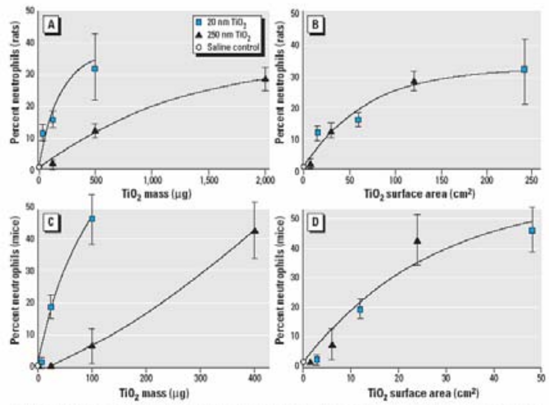

Figure 4. Percentage of neutrophils in lung lavage of rats (*A,B*) and mice (*C,D*) as indicators of inflammation 24 hr after intratracheal instillation of different mass doses of 20-nm and 250-nm TiO_2 particles in rats and mice. (*A,C*) The steeper dose response of nanosized TiO_2 is obvious when the dose is expressed as mass. (*B,D*) The same dose response relationship as in (*A,C*) but with dose expressed as particle surface area; this indicates that particle surface area seems to be a more appropriate dosemetric for comparing effects of different-sized particles, provided they are of the same chemical structure (anatase TiO_2 in this case). Data show mean ± SD.

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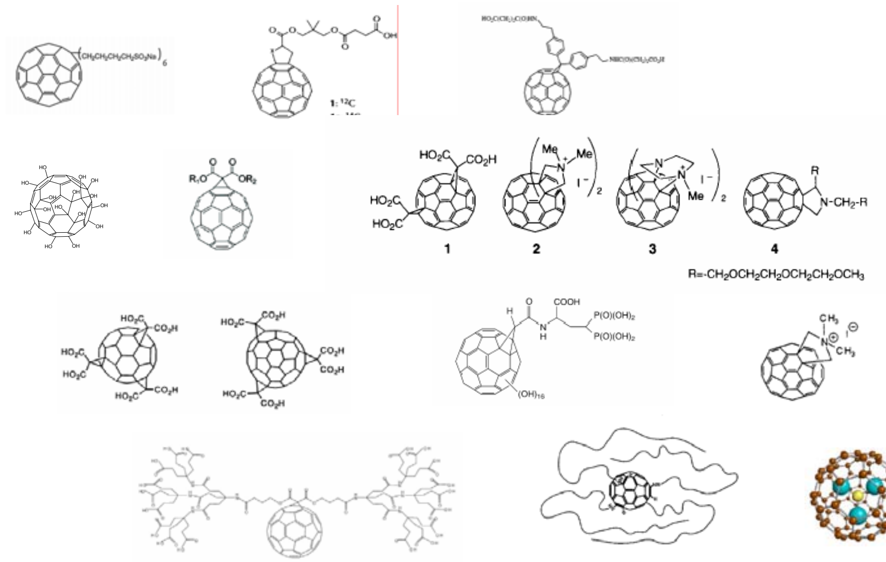
Diversity of surface chemistry - fullerenes



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Impact of surface chemistry on in vitro cytotoxicity

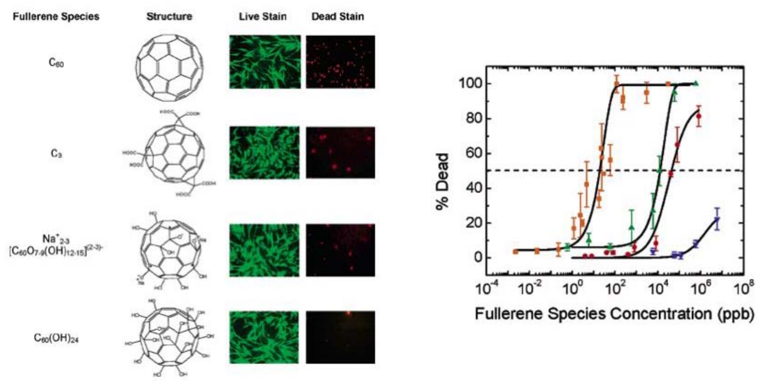


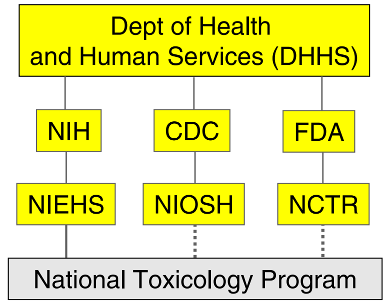
Figure 1. Differences in the structure and cellular activity of nano-C_{60}, C_3, $Na^+_{2-3}[C_{60}O_{7-9}(OH)_{12-15}]^{(2-3)-}$, and $C_{60}(OH)_{24}$. The structure of each fullerene species is shown in the table, as well as the live and dead stains. (Bottom) The differential cytotoxicity of nano-C_{60} (■) as compared to C_3 (▲), $Na^+_{2-3}[C_{60}O_{7-9}(OH)_{12-15}]^{(2-3)-}$ (●), and $C_{60}(OH)_{24}$ (▼) in human dermal fibroblasts. Cells were exposed to toxicant for 48 h.

Sayes et al 2004, Nanoletters 4:1881-1887

National Toxicology Program (NTP)

- Established in 1978 in DHHS
- Headquartered at NIEHS
- Thousands of environmental and industrial chemicals, pharmaceuticals, etc. evaluated in comprehensive toxicology studies
- Not a "regulatory" agency
  - Public database
  - >600 cancer bioassays
- Research on "nominations"
  - Chemicals/Exposures/Issues
  - Multidisciplinary research teams
- GLP compliant "testing"
  - CRO contracts, not research grants
- Risk assessment activities-Report on Carcinogens, CERHR
- Validation of alternate models

ntp.niehs.nih.gov



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NTP Nanotechnology Safety Initiative

http://ntp.niehs.nih.gov/go/nanotech

- Scientific Focus
  - Examine how nanomaterials enter, travel through, and deposit in the body
  - Identify key components that govern nanomaterial safety
- Current Activities
  - Quantum dots; Pharmacokinetic studies
    - Impact of surface chemistry
  - Titanium dioxide; Dermal pharmacokinetics, and photo-cocarcinogenicity
    - Impact of coatings and crystal state
  - Carbon based fullerenes; Pulmonary and oral toxicity
    - Impact of size of aggregates
  - Dendrimers; Pharmacokinetics and biocompatibility
    - MOU with NCIs Nanotechnology Characterization Laboratory
    - Impact of size and surface chemistry
  - Single walled carbon nanotubes
    - NIEHS-NIOSH interagency agreement

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NIEHS Extramural Research - Fundamentals

- Scientific Focus
  - To understand at the cellular and molecular levels the biological response to the quantum properties of nanoscale materials
- RFA-FY06-Human Health Effects of Manufactured Nanomaterials
  - Joint solicitation between EPA, NSF, NIOSH, NIEHS/NIH
  - Funded three applications
    - Transmembrane transport
    - Cardiovascular toxicity
    - Oxidative stress
- RFA-FY07-Manufactured Nanomaterials: Physico-chemical Principles of Biocompatibility and Toxicity
    - NIEHS lead with additional partners
      - NCI,NEI, NHGRI, NIDCR, NIGMS, and EPA, NSF, NIOSH
    - Optional International component
- Primary contact- Sally Tinkle tinkles@niehs.nih.gov

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Extramural Research - Enabling technologies

- Environmental Sensors
  - Develop deployable sensor devices for a broad range of environmental exposures
- Biological Sensors
  - Develop and apply technologies to link exposure with disease etiology
- Intervention devices
  - Drug delivery devices and therapeutic nanoscale materials
- Remediation devices
  - Primary disease prevention through the elimination of exposure
    - Catalysis or chelation

- Primary contact- David Balshaw balshaw@niehs.nih.gov

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Future Directions

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Impediments to Progress

- Specific nanomaterials with highest exposure potential not well known, thus difficult to identify which materials are most important to study
- Proprietary information developed by industry not available
- Availability of "well-characterized" nanomaterials
- Limitations in interpretation of current published data
  - Varied quality of characterisation in publications
- Lack of consensus about merits of in vitro approaches
- Characterization of materials more difficult than anticipated
  - Analytical infrastructure is distributed
  - Analyses of nanomaterials in wet systems is not "routine"
  - Methods to detect nanomaterials in tissues or cells
- Communication and coordination within distributed multidisciplinary teams

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Links to Additional Resources

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