Environmental Guidelines for Nanotechnology

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An Interactive Qualifying Project (2010)

Nanosilver

Toxicity

- Mostly acute toxicity studies
- Overall poor consistency
- In vivo: Mammal cells: Minimum LC_{50} = 0.53 mg/l (28 h)
- In vitro: Rat: No observed effect (515 μg/m^3 in air)
  Oysters & fish: Minimum LC_{50} = 34.6 μg/l (96 h)
- Comparative: Nano ≈ Ionic
  Coated > Uncoated
  Large vs. Small?
- Mechanism: Oxidative stress
  "Trojan Horse"?

Environmental

- Reduced or no toxicity in simulated environment
- Toxicity increased by detergent and antibiotics
- 3-14% into water from consumer products

Risk Assessment

Production		Release		Remaining		Surface Water		Accumulation Time		Concentration
800 t/a	×	14 %	×	100 %	/	37200 km^3	×	20 a	=	6.0×10^{-5} mg/L
4.7 t/a	×	3.2 %	×	5 %	/	189900 km^3	×	1 a	=	4.0×10^{-11} mg/L

$$c_{allowed} = EC_{50,min} / 1000 = 3.46 \times 10^{-5} \text{ mg/L}$$

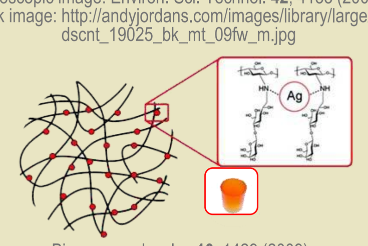
$$c_{pred,high} = 6.0 \times 10^{-5} \text{ mg/L}$$

$$c_{pred,low} = 4.0 \times 10^{-11} \text{ mg/L}$$

Risk Mitigation

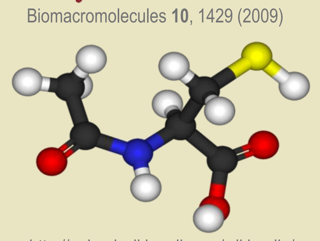
Microscopic image: Environ. Sci. Technol. **42**, 4133 (2008)
Sock image: http://andyjordans.com/images/library/large/dscnt_19025_bk_mt_09fw_m.jpg

- Silver-retaining socks
  Larger particles incorporated into fabric matrix; non-oxidizing detergent



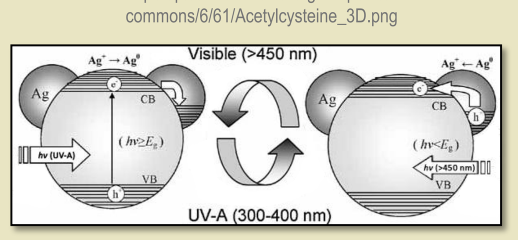
Biomacromolecules **10**, 1429 (2009)

- Silver-trapping gels
  Polysaccharide or carbopol gels: Antibacterial but non-toxic



http://upload.wikimedia.org/wikipedia/commons/6/61/Acetylcysteine_3D.png

- Nanosilver-binding ligands
  Sulfur-containing ligands:
  Sulfide ion or *N*-acetyl-L-cysteine

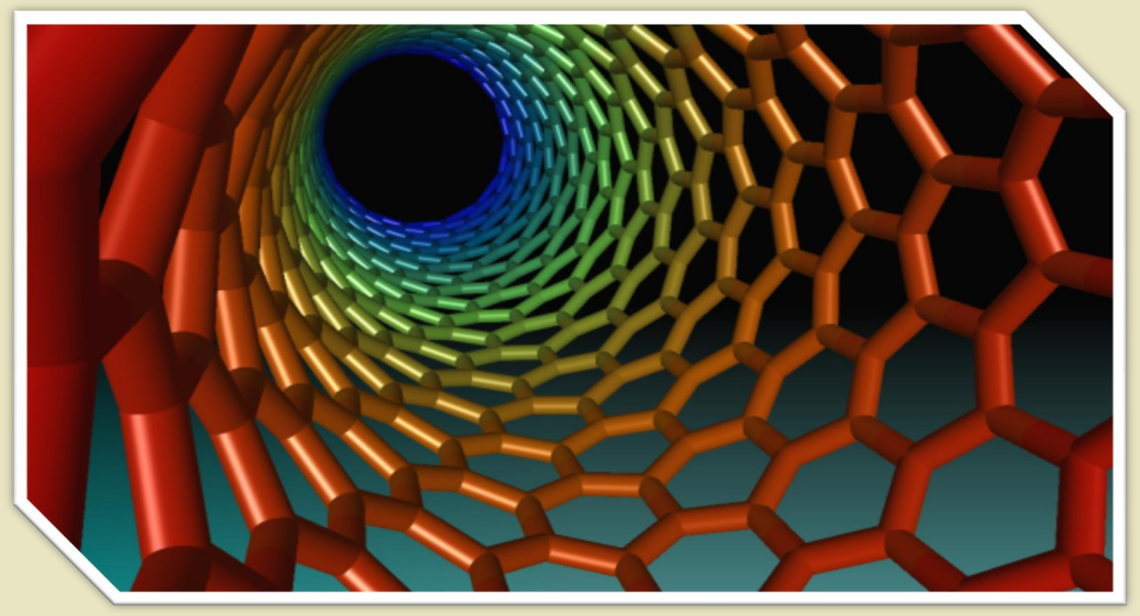


Small **5**, 341 (2009)

- Photo-switchable nanosilver
  Nanosilver on TiO_2 template
  Antibacterial activity can be switched on and off by light irradiation

Introduction

Engineered nanoparticles have shown great promise in medicine, electronics, physics, and environmental science. In particular, nanosilver has been gaining popularity in consumer products as an antibacterial agent. Carbon nanotubes, an excellent material for electronic devices, are also expected to be widely produced and used in the near future.



Carbon nanotube model.
http://geoffhutchison.net/gallery/main.php?g2_view=core.DownloadItem&g2_itemId=363&g2_serialNumber=2

However, the possibility of environmental risks from these nanoparticles has raised concern, which has motivated regulations and guidelines for their manufacturing and usage. To date, these efforts are still at a preliminary stage, largely because the level of environmental risk from nanoparticles has not been well characterized.

Guidelines for Nanosilver

- Research and application of risk mitigation strategies
- Research priorities: In vivo studies on environmentally relevant species
  Comparative toxicity and mechanism
  Human dermal exposure
  Environmental transport and fate models
  Environmental monitoring tools
- Production data: Forceful stewardship program by government
- Consumer awareness: Companies should label products as "Contains nanosilver"

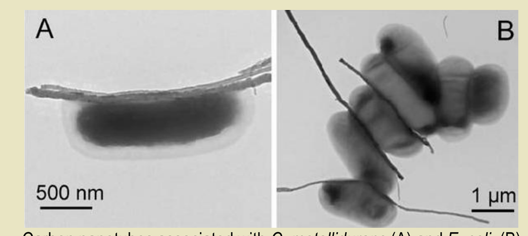
Guidelines for Carbon Nanotubes

- Mitigation: Antioxidant surfactant, tocopheryl polyethylene glycol succinate (TPGS), prevents oxidative damage to cell membranes
  Safe surfactant for "green" processing of carbon nanomaterials
- Research priorities: More studies on long term environmental fate and transport
  Comparative toxicity and mechanism
  More in vivo studies on environmentally relevant species
  Better standardization of models and characterization
- More green manufacturing methods
- Data collection from government

Carbon Nanotubes

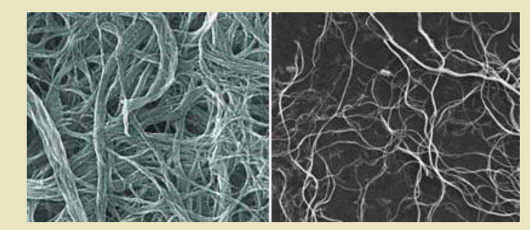
Toxicity

- Roughly 200 studies are available on nanotube toxicity.
- The majority of the reviewed papers report that nanotubes are toxic.
- Mostly acute toxicity studies on lung cells and macrophage cells, and respiratory toxicity studies on rats and mice.
- <u>Toxicity Mechanisms of Carbon Nanotubes</u>
  - Interaction between nanotubes and bacteria, damage to cell membrane.
  - Depletion of micronutrient contents in cell culture



Carbon nanotubes associated with *C. metallidurans* (A) and *E. coli*. (B)
Environ. Sci. Technol. **42**, 7528 (2008)

  - Free radical generation by scavenging activity.
  - Effect of physical and chemical properties (surface area, shape, length, solubility, functionalization, etc.)
  - Effect of metal catalysts.
- <u>Magnitude</u>
  - Lowest median lethal concentration:
    1.04 mg/l in algae; 22 μg/ml in macrophage (in vitro)
- <u>Comparative</u>
  - Toxicity similar to asbestos?
  - What role do catalysts and purification methods play?



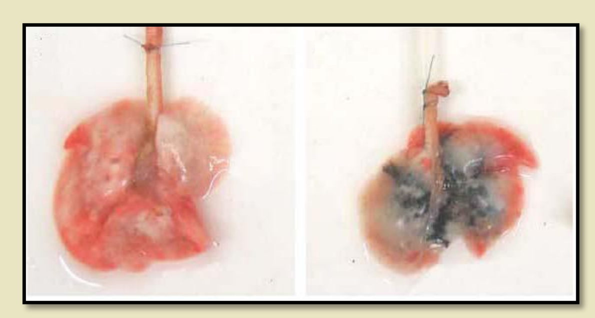
Carbon nanotubes (left) and chrysotile 'A' standard asbestos (right) both exhibit large length to diameter ratios.
http://www.physorg.com/news141048611.html (left)
http://usgsprobe.cr.usgs.gov/picts2.html (right)

Environmental

- Showed decreased toxicity after 2.5-7 years of exposure to natural organic matter.
- Settle more quickly in water without natural organic matter.

Risk Assessment

- Most nanotubes that are ingested are purged and not retained by the body.
- The respiratory risk that is posed is not well understood due to a lack of studies on long term biopersistence.



Rat lungs exposed to 5 mg of MWCNT (left) and ground MWCNT (right)
Toxicology and Applied Pharmacology **207**, 221 (2005)