Nanotechnology and the Environment: Benefits and Risks
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**Research**
- Theme 2: Nanoparticles for Bioengineering

**Education**
- Theme 1: Nanoscience at the Wet/Dry Interface
- Functional Nanoparticle

**Outreach**
- Theme 3: Nanoparticles & Environmental Engineering

Prof Vicki Colvin, Director
Established in 2001
International Council on Nanotechnology

INCLUSIVE
Multistakeholder cooperation

GLOBAL
International perspective

TECHNICAL
Grounded in science

PROACTIVE
Stewards for sustainability
What is Nanotechnology?

Nanotechnology is the study and use of materials with nanometer-scale dimensions.

Mountain | Child | Ant | Bacterium | Sugar Molecule (45 atoms)
---|---|---|---|---
1 kilometer (1000 m) | 1 meter (1 m) | 1 millimeter (0.001 m) | 1 micrometer (0.000001 m) | 1 nanometer (0.000000001 m)

1 meter (1 m)
Nanomaterials

Materials

~1-100 nm

Special properties*
**Different Types of Nanomaterials**

Engineered nanomaterials are very diverse with near limitless tunability

<table>
<thead>
<tr>
<th>Naturally Occurring</th>
<th>Human Origin (incidental)</th>
<th>Human Origin (engineered)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest fires</td>
<td>Cooking smoke</td>
<td>Metals</td>
</tr>
<tr>
<td>Sea spray</td>
<td>Cooking smoke</td>
<td>Quantum dots</td>
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<tr>
<td>Mineral composites</td>
<td>Diesel exhaust</td>
<td>Buckyballs/Nanotubes</td>
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<tr>
<td>Volcanic ash</td>
<td>Welding fumes</td>
<td>Industrial effluents</td>
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<tr>
<td>Viruses</td>
<td>Industrial effluents</td>
<td>Sunscreen pigments</td>
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<td></td>
<td>Sandblasting</td>
<td>Nanocapsules</td>
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</tbody>
</table>

Nanotechnology
Size-Dependent Properties

Fe₃O₄, Magnetite (4 nm)  
CdSe (8 nm)  
Gold (~ 10 nm)

Magnetism  
Emission  
Reactivity
Special [chemical, physical, electrical, mechanical, thermal] properties

Special BIOLOGICAL, ENVIRONMENTAL properties
Balancing the Benefits and Risks

**Applications:**
Enhanced or new capabilities to address existing and future environmental problems.

**Implications:**
Create the information and models needed to use nanomaterials in a sustainable manner.
Beneficial Interactions

Cancer Therapy

J. West et al.

Tumor Detection

R. Drezek et al.

Water Treatment

V. Colvin et al.
Pilot Project Tests Nanoparticle-Enabled Water Treatment & Reuse

“NanoRust” and novel derivatized fullerenes to remove hazardous water pollutants in municipal systems

Guanajuato, Mexico
(UN Heritage, pop. 80,000)

Grad Student Jesse Farrell

Wastewater Treatment Plant

- First known test of nanoparticles in municipal water and wastewater treatment
- Test bed will explore (1) using a sand-nanomagnetite in-line filter to remove arsenic in a well field, and (2) wastewater photo-disinfection with fullerenes
- Partnership with Municipal Water and Sewerage Authority of Guanajuato.
- Project Team: Alvarez, Li, Tomson, Lou, Colvin

Grad Student Jesse Farrell
Bimetallic Nanoparticles for Reductive Catalytic Treatment

**Mixed metal nanocrystals can reduce and detoxify chlorinated solvents such as TCE**

- Pd-on-Au bimetallic NPs break down chlorinated compounds
- Pd catalysts work; Pd-on-Au catalysts work 100x better
- Being tested on contaminated DuPont site
- **Project Team:** Wong, Alvarez
Potential Targets of Risk

Workers

Consumers

Environment

What is known about the impacts of engineered nanomaterials?
Environmental, Health and Safety (EHS) research has made up 3-7% of the federal US nanotechnology budget.
Cataloguing and Discussing the Research

- Monthly updates
- Over 3900 records
- Backgrounders on key literature

“This paper makes a major contribution to the literature …”

http://icon.rice.edu/VirtualJournal.cfm
EHS Publication Pace is Increasing...

...but exposure assessment lags behind

Source: http://icon.rice.edu/report.cfm
A Sampling of the Hazard Literature

Lung
- SWCNT and ultrafine TiO$_2$—Fibrosis
- Up to 50% of inhaled NPs may deposit in gas exchange region

Cardiovascular
- Air pollution epidemiology
- Inflammation

Brain/CNS
- Nose to brain pathway
Info Needs for Predicting Nano Impacts

Towards Predicting Nano-Biointeractions:
An International Assessment of Nanotechnology Environment, Health and Safety Research Needs

Towards Predicting Nano-Biointeractions (January 2007)
- Need tools and models able to describe dynamic nature of NMs throughout lifecycle
- Need to correlate the functional properties of NMs with potential for biointeraction

Towards Predicting Nano-Biointeractions (June 2007)
- Need models for how NMs properties control biointeractions at their surface
- Need independent validation of NM dose and dose rate

Models capable of predicting nano-biointeractions may take 10 years

http://tinyurl.com/cbxogv
Environmental Research Constitutes Only 7% of NanoEHS Literature

Source: http://icon.rice.edu/report.cfm
Nanoparticle Modifications in the Environment

TYPE 4: Degradation and transformation mechanisms
- Dissolution
- Chemical Reaction

TYPE 3: Physical attenuation mechanisms
- Aggregation
- Deposition

TYPE 2: Surface modification
- Desorption
- Adsorption

TYPE 1: Persistent nanomaterials
- NOM interactions

NOM = natural organic matter

- Microbial activity
- biofilm
- CO₂, C(4)
Top Needs to Advance the Eco-Responsible Design and Disposal of Engineered NMs

Eco-Responsible Design

- Metrology
- Structure-Activity Relationships
- Predictive Modeling of Multimedia Fate and Transport
- Bioavailability and Effects

Eco-Responsible Disposal

- Release and Exposure Scenarios
- Reclamation, Regeneration and Reuse of Nanomaterials
- Emerging Issues for Environmental Protection Infrastructure
- Regulatory Framework for Nanomaterial Disposal

March 2009
ACS Nano, 2009, 3 (7), 1616-1619
July 2009
NSF CBET-0903936
Mildly acidic or alkaline conditions lead to QD breakdown, release of contents; neutral pH does not kill bacteria

- nC$_{60}$ antibacterial activity due to direct oxidation
- Sorption of nC$_{60}$ to natural organic matter removes toxicity in soil
- Degradation of QDs releases toxic metals
- Project Team: Alvarez (CEVE), Colvin (CHEM)

Potential Targets of Risk

Workers

Consumers

Environment
Stakeholders Seek Info on Good Practice

Comprehensive, international survey of handling practices in the nanotech workplace

“Surveyed organizations reported that they believe there are special risks related to the nanomaterials they work with...and that they are actively seeking additional information on how to best handle nanomaterials.”

Survey respondents were nanomaterial manufacturers, users and researchers in industry, academia and independent and government labs from North America, Europe, Asia and Australia.

SOURCE: http://tinyurl.com/icosurvey
Some Resources for Handling Nano

**US**
- DOE NSRC
- NIOSH

**Canada**
- IRSST

**Europe**
- NanoSafe2
- BAUA

Standards:
- E2535-07
- ISO/TR 12885
- PD 6699-2:2007
Common Messages

• Nanomaterial behavior may differ from that of non-nanoscale analogs
• Some nanomaterials may pose health risks if exposure is present
• Hazard and exposure data do not yet provide a clear picture of risk

MINIMIZING EXPOSURE IS PRUDENT
Barriers to Information Sharing
How do we get **Timely**, **Practical**, **High-quality** information out to ALL the target populations?
The GoodNanoGuide

Welcome to the GoodNanoGuide

The GoodNanoGuide is a collaboration platform designed to enhance the ability of experts to exchange ideas on how best to handle nanomaterials in an occupational setting. It is meant to be an interactive forum that fills the need for up-to-date information about current good workplace practices, highlighting new practices as they develop.

- Protected Internet site on occupational practices for the safe handling of nanomaterials
- Multiple stakeholders contribute, share and discuss information
- Modern, interactive, up-to-date
- Launched 1 June 2009

http://GoodNanoGuide.org
Interacting with the GoodNanoGuide

**VIEW**
No Registration Required

**COMMENT**
Register as a Community Member

**CONTRIBUTE**
Register as an Expert Provider
How Content is Organized

- Basic
  - Introduction to Nanotechnology
  - Nomenclature and Glossary

- Intermediate
  - OHS Reference Manual

- Expert
  - Expert Matrix
  - Specific Protocols
The GoodNanoGuide provides both environmental, health and safety ("EHS") Protocols and an EHS Reference Manual. The EHS Reference Manual outlines the approaches taken by professionals using research about nanomaterials and other precedents to develop appropriate protocols and guidelines. The Manual is open for edit and comment and is organized into six sections sequenced to conform with general industrial processes employed by professionals who investigate risks and develop protocols for mitigating risks.

**Section I - A Well-Defined Description of Work** - This is the important description of the specific work and EHS environment.

**Section II - Identify Hazard** - This requires use of the main concepts of nanomaterial physico-chemical characteristics, toxicology, ecotoxicology, and hazard classifications and EHS concepts to inform the consideration of the materials and factors that may constitute potential exposure and EHS risk from nanomaterials.

**Section III - Assess Potential Exposures** - This analysis of the range of locations, types of person(s) and exposure routes allows the professional to recommend practices for qualitative and quantitative exposure assessment.

**Section IV - Develop Risk Management Plan** - This deals with the elements of the Plan based on the principles of controlling and managing exposure and how to apply good EHS and control practices.

**Section V - Verify Control Measures** - Key to any EHS process is the need for the tools to evaluate the exposures, effectiveness of control measures and verification of procedures.

**Section VI - Periodically Re-Evaluate Good Practices** - Outlines the rationale for periodic reviews of the EHS protocols and exposure risks to allow for amendments and quality improvement over time.

**II. Identify Hazard**
- Physicochemical Characteristics
  - Particle Size and Size Distribution
  - Surface Area
  - Surface Chemistry or Activity
  - Other Physicochemical Characteristics
- Toxicity Characteristics
- Ecotoxicity Characteristics
- Hazard Class Assignment
- Hazard Communication Plan
Assessment should
- Look at the form of the nanoparticle
- Consider the entire process
GoodNanoGuide Goals

- Develop and publish more process-specific protocols
- Engage researchers, users, contributors or Implementation Committee members
- Sustain the GoodNanoGuide as an open-access resource

http://goodnanoguide.org
Conclusions

- Research on nano impacts is accelerating
- Many knowledge gaps need to be filled to ensure the sustainable use of nanomaterials
- Industry is a key stakeholder in nano impacts issues
Upcoming Events

5th Annual Green Chemistry and Commerce Council Innovators Roundtable
Sysco Corporation
1390 Enclave Parkway
Houston, Texas
April 26-28, 2010

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