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DEPARTMENT OF ENERGY AND MINERAL ENGINEERING

COLLEGE OF EARTH AND MINERAL SCIENCES

Engineered Nanomaterials for NASA: Managing Health and Safety Concerns (a user's perspective)

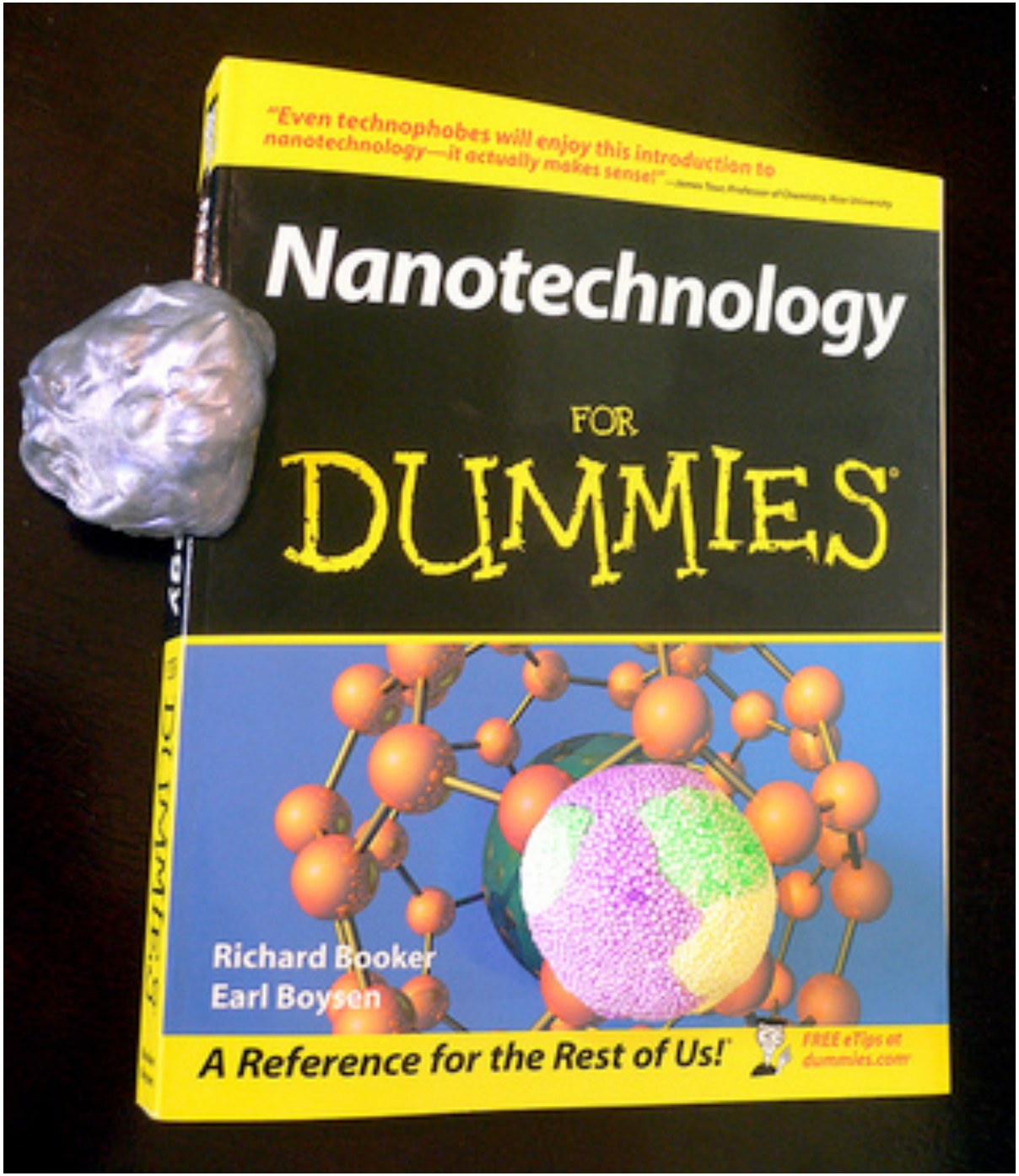
Dr. Randy L. Vander Wal

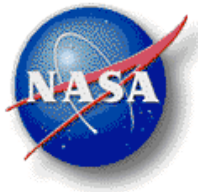
www.psu.edu

Acknowledgements:

The 2009 NASA Occupational Health Meeting for the Invitation and Support

The NSC c/o OAI, July 13-17th, Cleveland OH


"Even technophobes will enjoy this introduction to nanotechnology—it actually makes sense!"
Nanotechnology
FOR
DUMMIES
Richard Booker
Earl Boysen
A Reference for the Rest of Us!
FREE eTips at dummies.com



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Outline

I. Applications

II. Production

III. Illustrations of Engineered Nanomaterials

IV. Status Overview – (present day headlines)

V. Managing Health and Safety Concerns

VI. Conclusions

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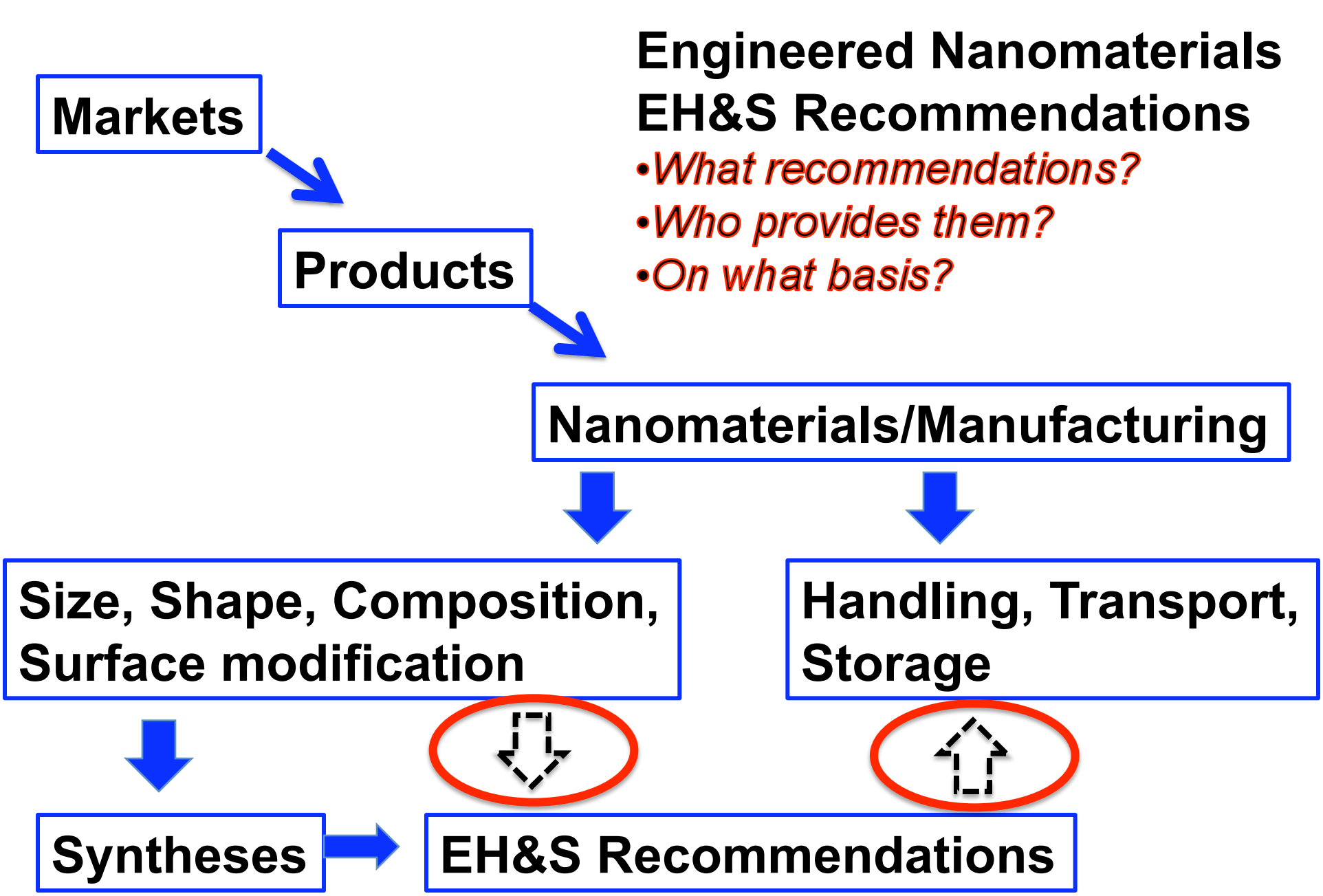
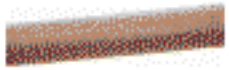

Engineered Nanomaterials
EH&S Recommendations
•What recommendations?
•Who provides them?
•On what basis?
Markets
Products
Nanomaterials/Manufacturing
Size, Shape, Composition,
Surface modification
Handling, Transport,
Storage
Syntheses
EH&S Recommendations

Ant
~ 5 mm

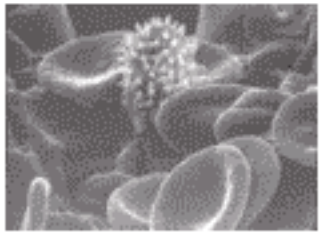
Dust mite
200 µm

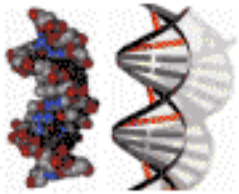


Human hair
~ 10-50 µm wide

Red blood cells with white cell

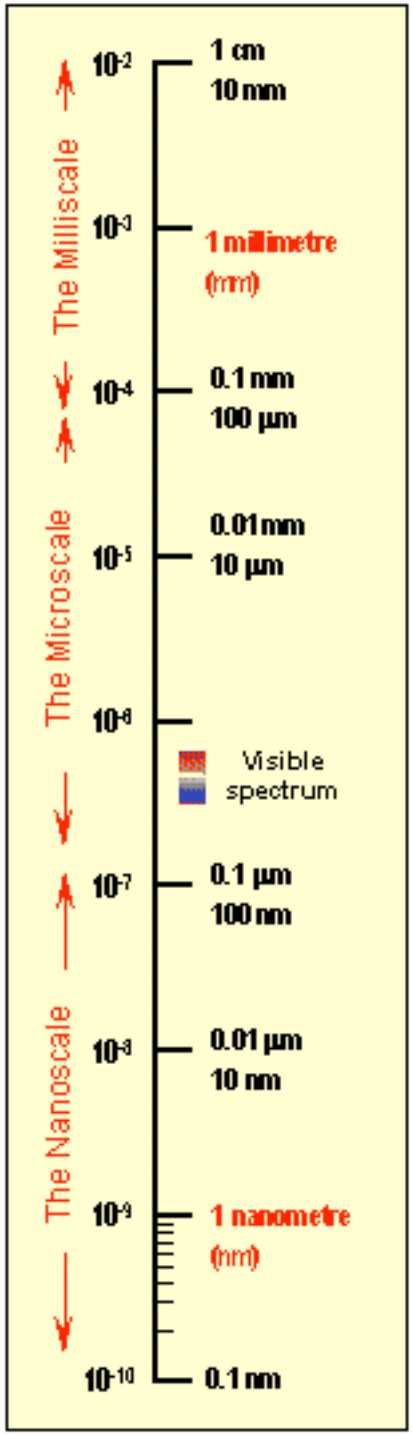
~ 2-5 µm





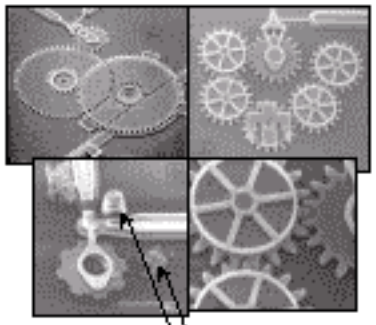
DNA
~2-1/2 nm

5 Atoms of silicon
1 nm



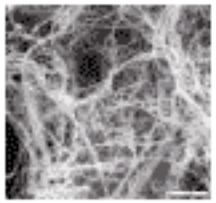
Head of a pin
1-2 mm

Micro Electro Mechanical Devices
10 -100 µm wide



Pollen grain

Red blood cells



Cellulose nanofibrils 20-100nm wide

Stacks of clay mineral platelets, each platelet with ~ 1nm thickness

Carbon nanotube
~2 nm diameter

NanoTech Markets

Nanotechnology – Definition

Nanotechnology is the ability to measure, see, manipulate and manufacture things usually between 1 and 100 nanometers

e.g. a human hair is roughly 10,000 nanometers wide.

Market Forecasts

In 2007, the global market for goods incorporating nanotechnology totaled $147 billion.

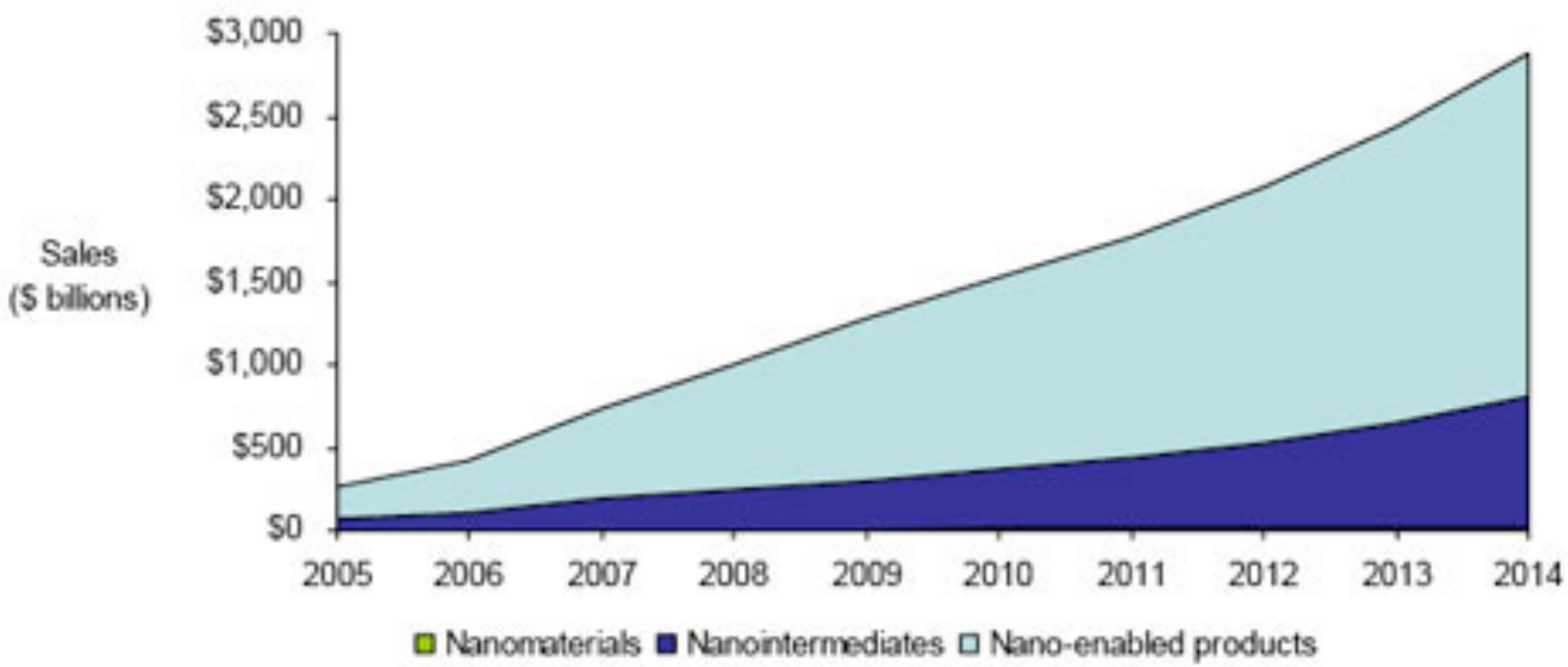
* Lux Research projects that figure will grow to $3.1 trillion by 2015.

* National Science Foundation's (NSF) "$1 trillion by 2015",

Evolutionary or Revolutionary Nanotechnology?

Nanomaterials: Application Fields

Nanomaterials: Markets



NanoTechnology for the Better

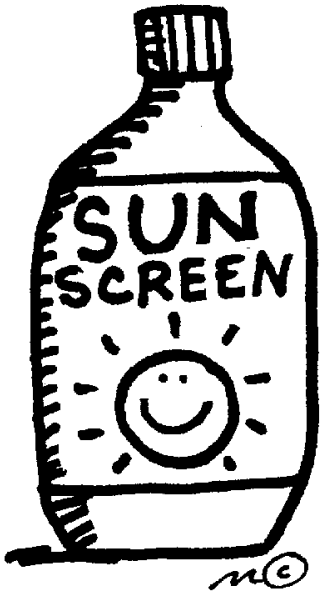
Cheap and clean energy
✓ Wind turbine blades
✓ Solar panels
✓ Battery technology

Clean Water
✓ Purification
✓ Detection of impurities

Pollution Reduction and Environmental Progress
✓ Nanoscale Ag with antibacterial properties

Improved Materials and New Products
✓ Baseball bats, tennis rackets &
✓ Thin films to make them water-repellent, anti-reflective, self-cleaning, ultraviolet or infrared-resistant, antifog, anti-microbial, scratch-resistant, or electrically conductive.

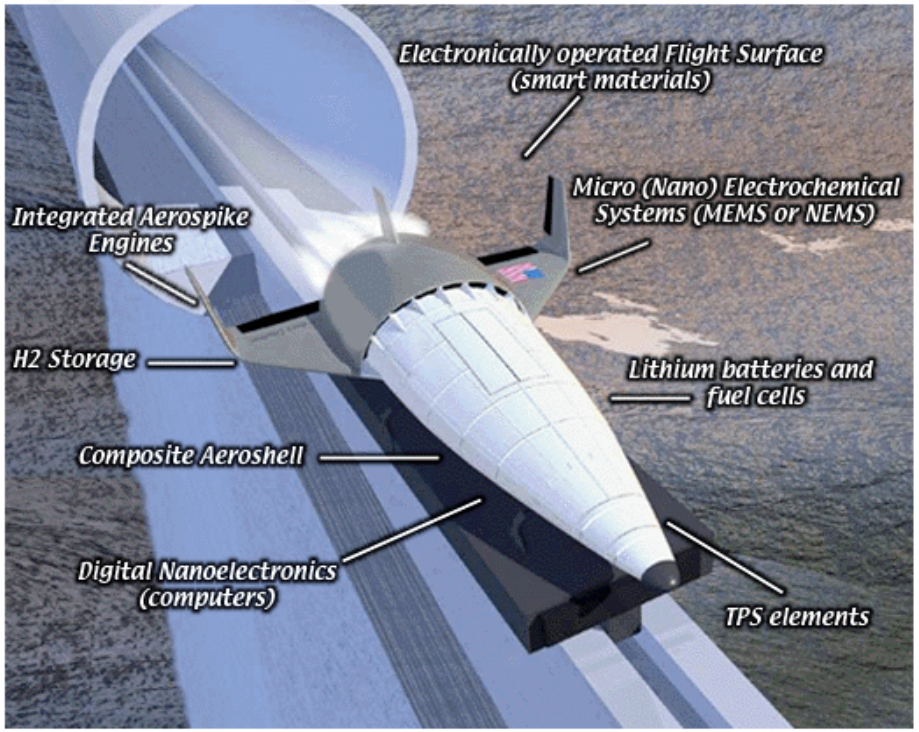
Nanomaterials: Commercial Products



EED 9000 X

Nanomaterial Enabled Technologies

Area	Under Development	In Market	Well-Established
Power/Energy	Nanocrystalline Ni and Metal hydrides for batteries * Dye sensitized solar cells * Anode/Cathode materials for fuel cells * Thermal control fluids	Environmental Catalysts Diesel additives	Automotive catalysts
Healthcare/ medical	* Drug delivery Inhalable drugs * Bone growth promoters Virus detection Anticancer treatments Coatings for implants	Sunscreens using ZnO, TiO2 Molecular tagging Quantum dots Drug carriers	Ag antibacterial wound dressings ZnO fungicide Au for biolabelling and detection MRI contrast agents



NASA Nanotechnology Goals

1. Mass reduction and miniaturization,

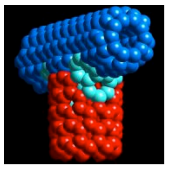
2. Robotic exploration of the solar system

3. Small economical spacecraft with high autonomy and improved capabilities.

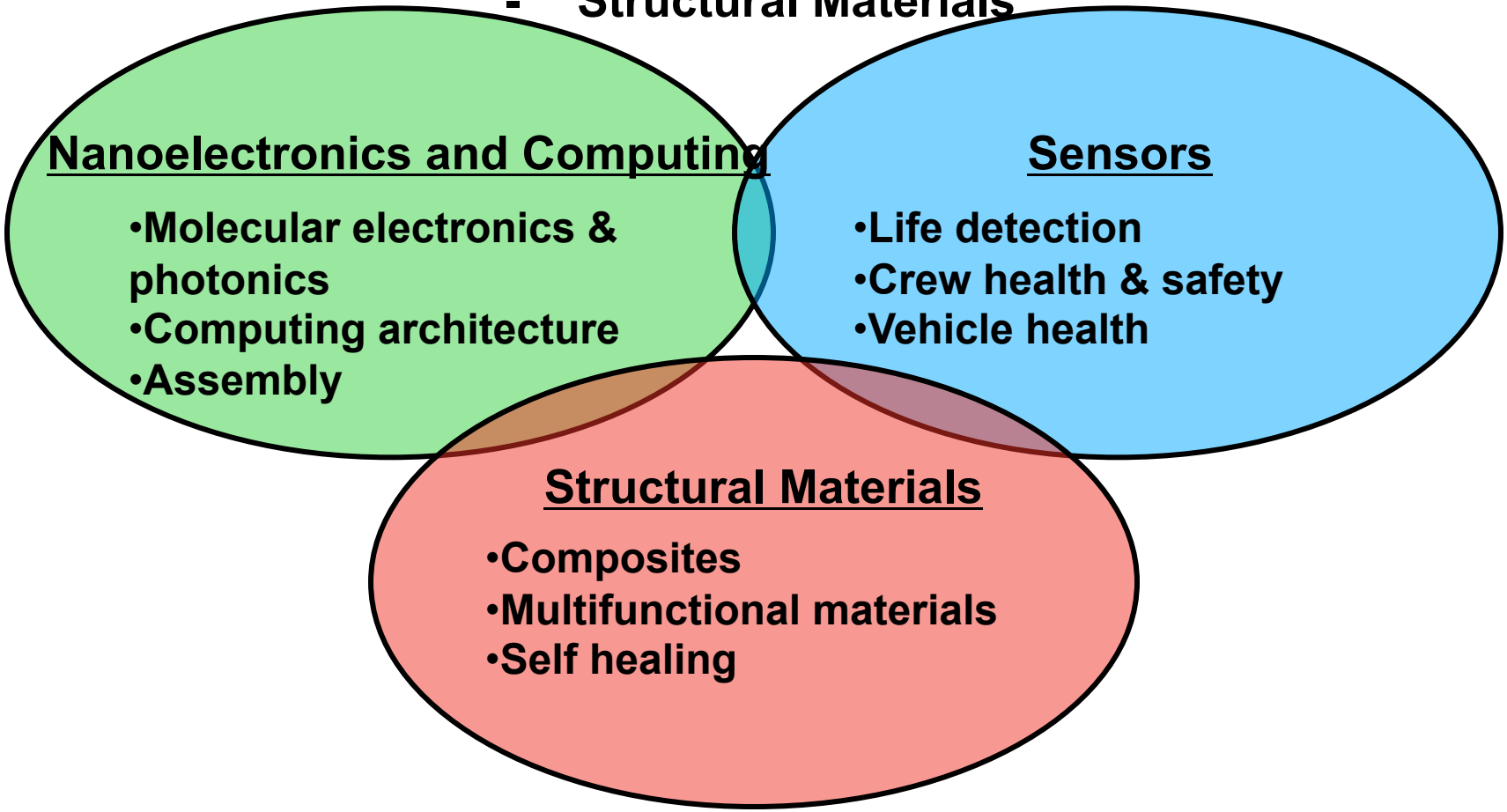
4. Medical diagnostics and therapy procedures for life support systems

Long-term and more complex manned space missions

NASA Nanotechnology Program Content



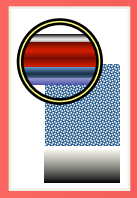
- Nanotechnology Program Elements
  - Nanoelectronics and Computing
  - Sensors
  - Structural Materials



NASA Nanotechnology Roadmap

C A P A B I L I T Y

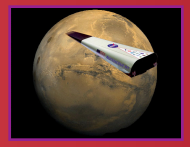
Multi-Functional Materials



High Strength Materials (>10 GPa)

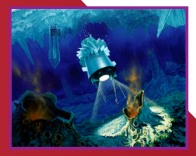
Reusable Launch Vehicle (20% less mass, 20% less noise)

Revolutionary Aircraft Concepts (30% less mass, 20% less emission, 25% increased range)



Autonomous Spacecraft (40% less mass)

Bio-Inspired Materials and Processes



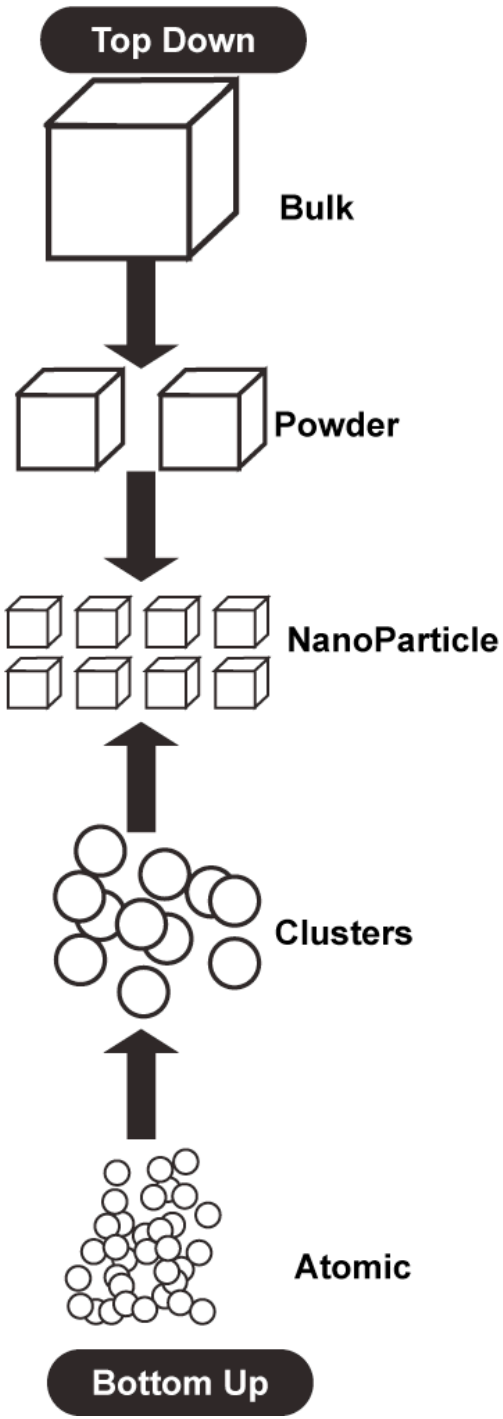
Adaptive Self-Repairing Space Missions

Increasing levels of system design and integration →

Materials	• Single-walled nanotube fibers	• Nanotube composites	• Integral thermal/ shape control	• Smart "skin" materials	• Biomimetic material systems
Electronics/ computing	• Low-Power CNT electronic components	• Molecular computing/ data storage	• Fault/radiation tolerant electronics	• Nano electronic "brain" for space Exploration	• Biological computing
Sensors, s/c components	• In-space nanoprobes	• Nano flight system components	• Quantum navigation sensors	• Integrated nanosensor systems	• NEMS flight systems @ 1 μW

2002 2004 2006 2011 2016

Nanomaterial Synthesis Approaches



Top Down Methods

Mechanical Grinding

Erocion

Bottom Up Methods

Aerosol Techniques

Chemical Precipitation

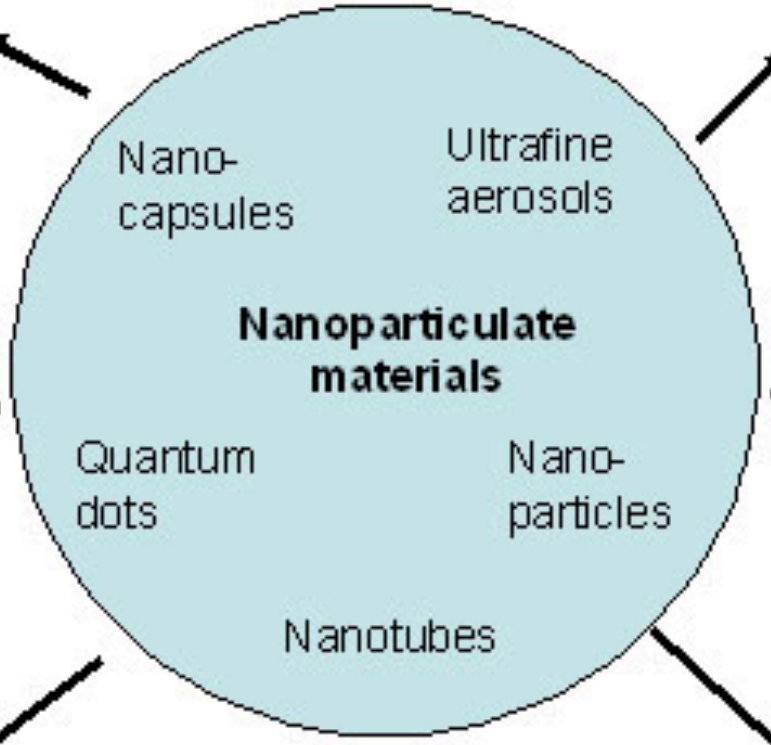
Gas Phase Agglomeration

Self Assembly

Nanodiversity

Origin
Natural
Unintentionally released
Manufactured (old, new)

Dispersion in
Gases (aerosols)
Liquids (e.g. gels, ferrofluids)
Solids (e.g. matrix materials)



Chem Composition
Metals/metal oxides
Polymers, carbon
Semiconductors,
Biomolecules
Compounds…

Shape/Structure
Spheres
Needles
Platelets
Tubes

Aggregation state
Single particles
Aggregates
Agglomerates

Surface modification
Untreated (as obtained in production process)
Coated (e.g. conjugates, polymeric films)
Core/shell particles (e.g. spheres, capsules)

Nanotech Safety

NRC report blasts federal research strategy for addressing risks of nanomaterials

Britt E. Erickson

THE FEDERAL GOVERNMENT'S research plan for assessing the potential environmental, health, and safety (EHS) risks of nanomaterials is **inadequate**, concludes a new report from the National Research Council.

Nanotech safety high on Congress' priority list

New House bill addresses need for more risk research, oversight

Washington, DC – The House Science and Technology Committee today introduced legislation that highlights the growing attention on Capitol Hill to the need to strengthen federal efforts to learn more about the potential environmental, health and safety (EHS) risks posed by engineered nanomaterials. *January 2009*

Nanotech Safety

1. Warheit et al. Dupont, 2003

* Administered a bolus via intratracheal instillation of CNTs in buffered saline solution
* Rats died within minutes of injection

(Toxicity of CNTs or Suffocation?)

2. Donaldson et al. University of Edinburgh, 2007

* SWNTs injected into the peritoneal cavity of mice invoked an immune reaction with inflammation and lesions developing (failed phagocytosis).

* Used 0.5% wt. of BAL to maintain suspended CNTs

* Study only lasted 7 days.

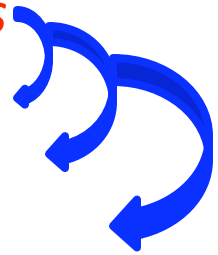
Nanotech Safety

Nanocarbons – a partial listing:

SWNTs, DWNTs, MWNTs, Nanofibers, Micro-coils, Nano-onions, Fullerenes, Nanohorns, Graphene, Carbon dots, Nano-diamonds

Related Issues:

1.Metallic impurities
2.Functional groups
3.Disordered carbon
4.Varied lengths
5.Dispersing agents



Purity of CNTs – size, type, composition and morphology

Present Day Status – EH&S

- Non-governmental initiatives such as the GoodNanoGuide and the ResponsibleNanoCode are helping businesses address nanomaterial safety.

- **But there is an absence of standards and toxicology results vary widely**.

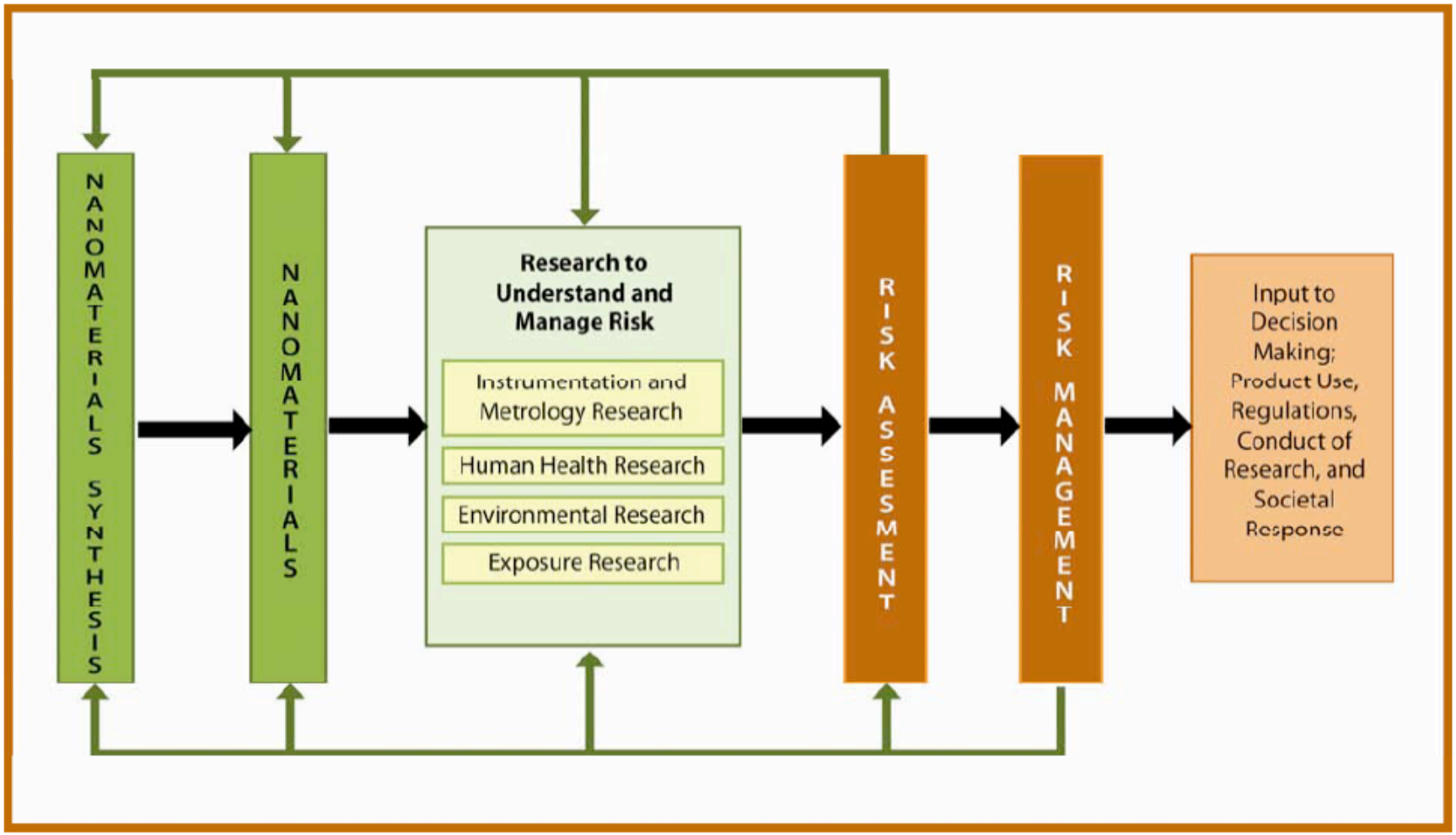
- Agency requests for voluntary information largely have failed, e.g. Canada, & U.S. Potential in Europe to require mandatory reporting for > 1 kg quantities.

- On 29 June, the EPA tightened its regulatory oversight on specific types of carbon nanotubes.

How to predict and manage the potential risks associated with existing nanomaterials?

"Get this right, and consumers and industry stand to gain from the development of safe, sustainable new technologies. But get it wrong, and everyone is likely to lose out." (*Nature* **460**, 174, published online 9 July 2009).

Role of Nanotechnology EHS Research in Risk Management of Nanomaterials



Source: The National Nanotechnology Initiative

Managing the Health and Safety Concerns Associated with Engineered Nanomaterials

- Engineered nanoparticles: one dimension between 1 and 100 nanometers.

- Unique physical and chemical properties

- Little is known about effects on human health.

- Research has shown physicochemical including particle size, shape, surface area, charge, chemical properties, solubility, oxidant generation potential, and degree of agglomeration have biological consequences.

Until the results from research studies can identify characteristics posing health risks, precautionary measures are warranted.

Managing the Health and Safety Concerns Associated with Engineered Nanomaterials

Research Results to-date

◆Uptake via respiratory system, skin contact or ingestion

◆Nanoparticles can enter the blood stream, and translocate to other organs.

◆Equivalent mass doses of nanoparticles are more potent than large particles *in causing pulmonary in-flammation and lung tumors.*

◆Composition, crystal structure, and size of particles can influence their oxidant generation properties and cytotoxicity.

Research is needed to determine the key physical and chemical characteristics of nanoparticles that determine their hazard potential.

Managing the Health and Safety Concerns Associated with Engineered Nanomaterials

Working with Nanomaterials - Exposure routes

- Working with nanomaterials in liquids during pouring or mixing operations, or where a high degree of agitation is involved without adequate protection (e.g., gloves)
- Generating nanoparticles in non-enclosed systems
- Handling (e.g., weighing, blending, spraying) powders of nano-materials
- Maintenance on equipment and processes used to produce or fabricate nanomaterials
- Cleaning up spills, waste material & dust collection systems used to capture nanoparticles
- Machining, sanding, drilling, or other mechanical disruptions of materials containing nanoparticles

Managing the Health and Safety Concerns Associated with Engineered Nanomaterials

Exposure Assessment and Characterization

- *Until more information becomes available* (on the mechanisms underlying nanomaterial toxicity), it is uncertain what measurement technique should be used to monitor exposures in the workplace.

- Mass and bulk chemistry may be less important than particle size and shape, surface area, and surface chemistry (or activity) for some nanostructured materials.

- Current airborne nano-aerosol measurement techniques
  - * vary in complexity
  - * *can provide* useful information for evaluating occupational exposures
  - * *yet fail* to provide a comprehensive characterization with respect to particle size, mass, surface area, number concentration, and composition
  - * *few* of these techniques are readily applicable to routine exposure monitoring.

Managing the Health and Safety Concerns Associated with Engineered Nanomaterials

Precautionary Measures – To minimize exposure

1) Evaluate the hazard based on available physical and chemical property data, toxicology, or health-effects data

2) Assess the potential for exposure

3) Education and training in proper handling of nanomaterials (e.g., good work practices)

4) Establish criteria and procedures for installing and evaluating engineering controls (e.g., exhaust ventilation).

5) Systematically evaluating exposure potential to ensure that control measures are working

Managing the Health and Safety Concerns Associated with Engineered Nanomaterials

Precautionary Measures – To minimize exposure

✓*Who is responsible? (for evaluating, educating, establishing….*

✓*Are they qualified?*

✓*What are the metrics?*

✓*Are there related hazards?*

✓*If time and/or money are inadequate, then what?*

Are the hazards associated with raw materials, synthesis, storage, handling, transport or processing?

Managing the Health and Safety Concerns Associated with Engineered Nanomaterials

Risk Mitigation - Control Measures for Preventing Exposure

Presently: No guidelines on clothing or other ap-parel (e.g., gloves) *but reasonable lab attire!*

Future: Procedures for selecting proper personal protective equipment (e.g., clothing, gloves, respi-rators).

✓Implement engineering control techniques:

- source enclosures
- local exhaust ventilation systems
- HEPA filters should effectively re-move nanomaterials.

✓Good work practices can help to minimize worker exposures to nanomaterials.

- cleaning of work areas using HEPA vacuum pickup, wet wiping
- no consumption of food or beverages in workplaces where
- nanomaterials are handled, providing facilities for hand-washing
- showering and changing clothes

Safe Handling? ***Common Sense****!*

Unwarranted Fear?

Flickr: brainsluice

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Comments Suggestions Welcomed!

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Post-script: NanoTech Safety – Perspective

* Chemists & Biologists have dealt with naturally occurring nanoparticles all along.
e.g. molecules or viruses.

* Toxicologists have dealt with nanoparticles, e.g. carbon particles in combustion engine exhaust

* Tire manufacturers used nanoparticles, carbon black, to improve the performance of tires as early as the 1920s.

* Medieval artists used gold nanoparticles to achieve the bright red color in church windows (gold particles in nanometer size are red, not golden).

We are surrounded by, and made of, nanostructures – atoms and molecules are nanoscale.

So what is all the fuss about, and where do the risk issues come from all of a sudden?