Emerging Technologies: Risk Management with Limited Risk Assessment Information

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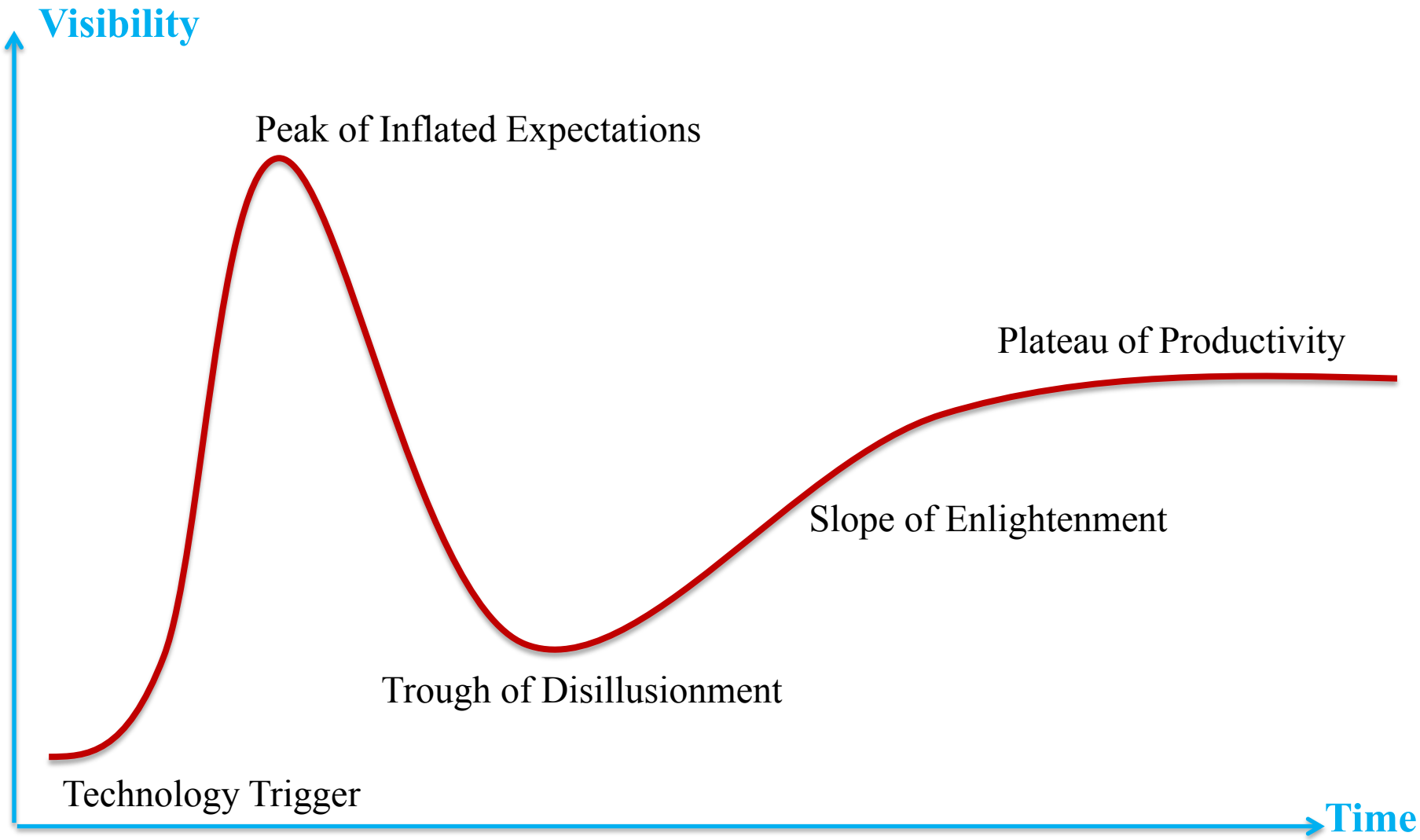
Overview

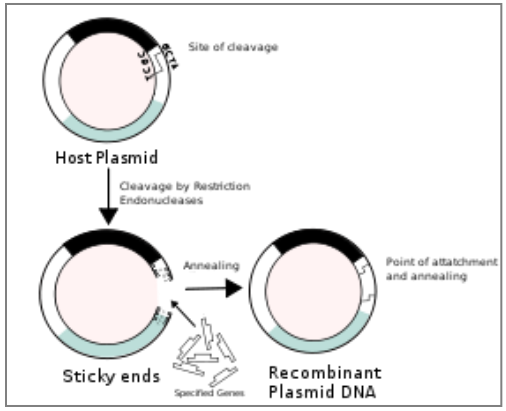
- Emerging Technology Phases
- Nanotechnology – why all the buzz?
- EH&S and other related issues
- Ramblings on Oversight and Governance of Nanotechnology

Emerging Technology Hype-Cycle Phases

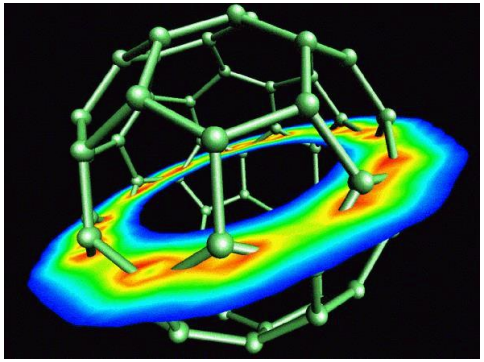


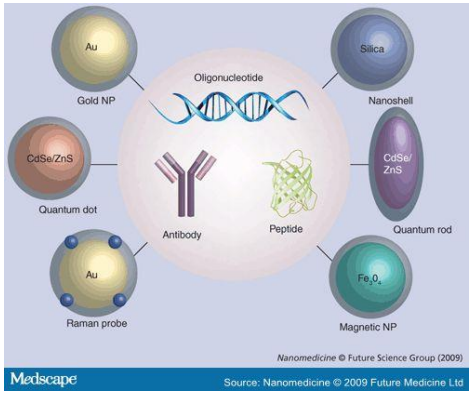
http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp

Examples of Emerged/Emerging Technologies

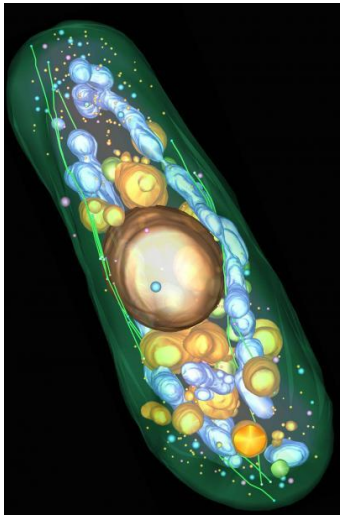


rDNA/Genetic Engineering 1970's





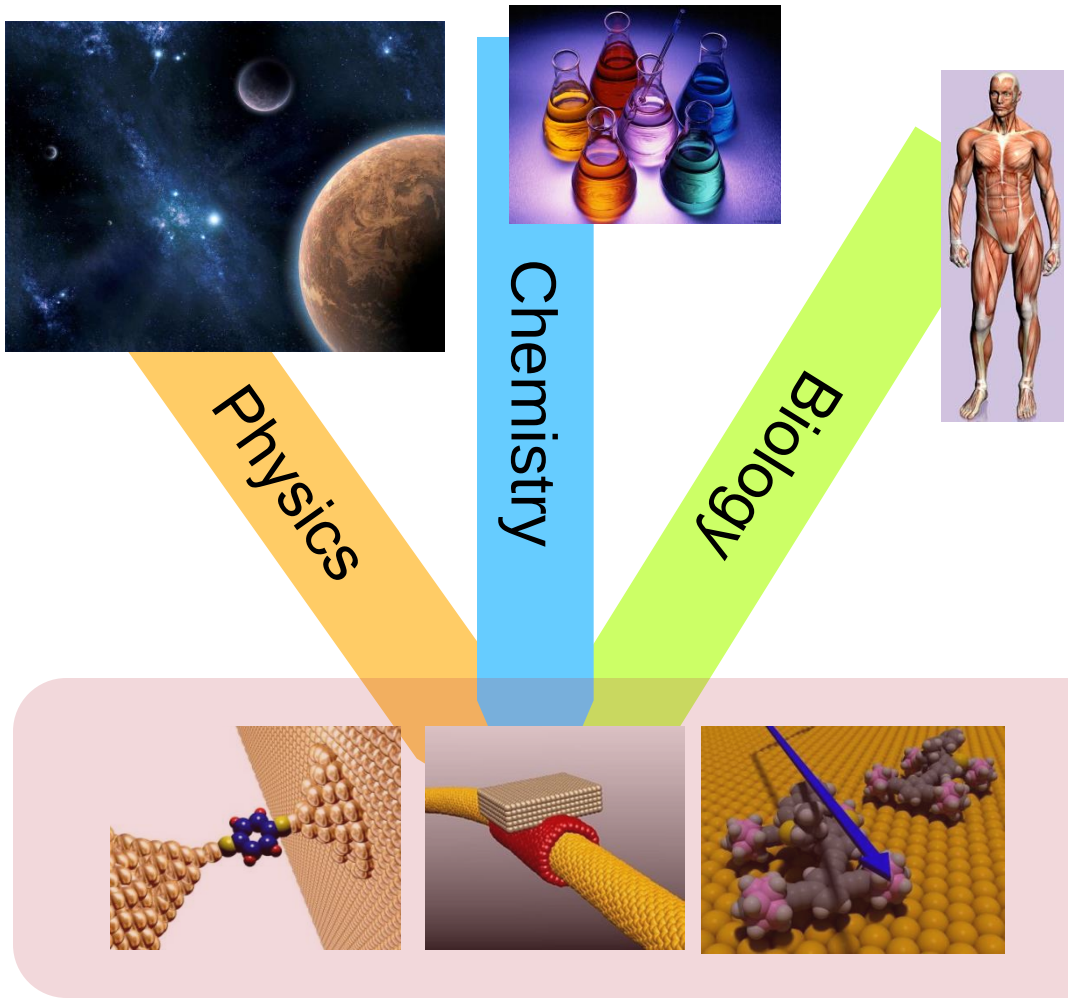
Nanomaterials 1990s



Synthetic Biology 2000s

Optogenetics 2010

Nanotechnology: Working at the Nanoscale



Nanoscale Science is where Physics, Biology and Chemistry fuse.

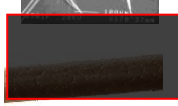
The Scale of Things

Things Natural

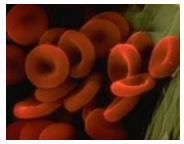
Ant
~ 5
mm

Dust mite
~200 μm

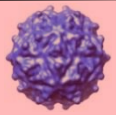
Human hair
~ 60-120 μm wide



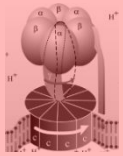
Red blood cells
~7-8 μm



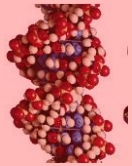
Pariacoto Virus
~40 nm diameter



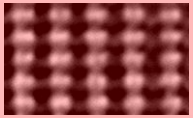
ATP synthase
~10 nm diameter



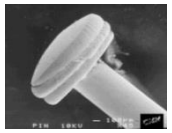
DNA
~2-1/2 nm diameter



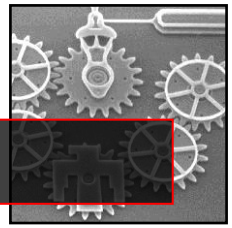
Atoms of silicon
spacing 0.078 nm



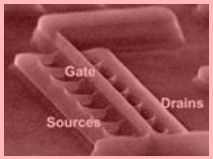
Things Manmade

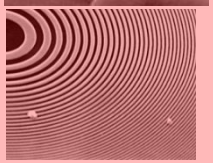


Head of a pin
1-2 mm

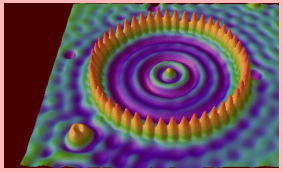


Micro Electro Mechanical
devices (MEMS)
10 -100 μm wide

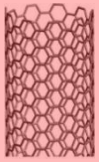




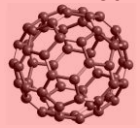
Zone plate x-ray "lens"
Outer ring spacing ~35 nm



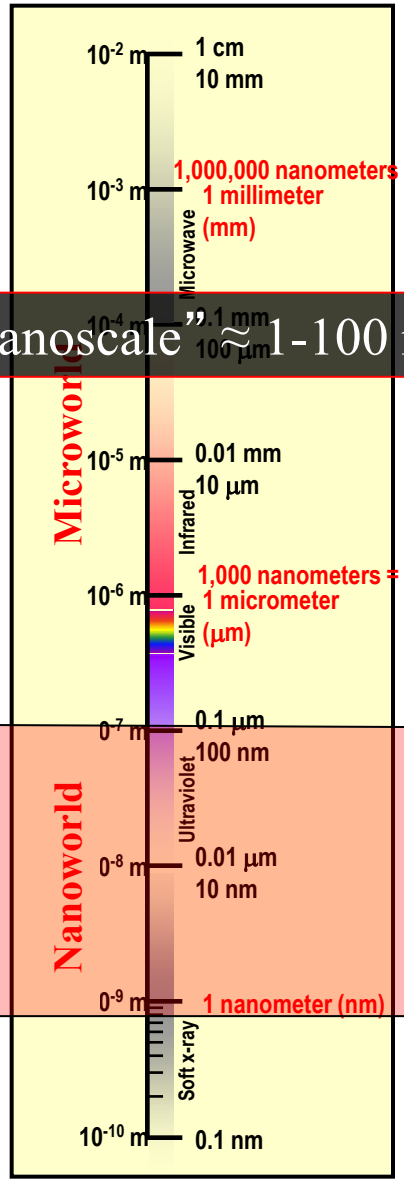
Quantum corral of 48
iron atoms on copper
surface
positioned one at a time
with an STM tip
Corral diameter 14 nm



Carbon nanotube
~1.3 nm diameter



Carbon buckyball
~1 nm diameter

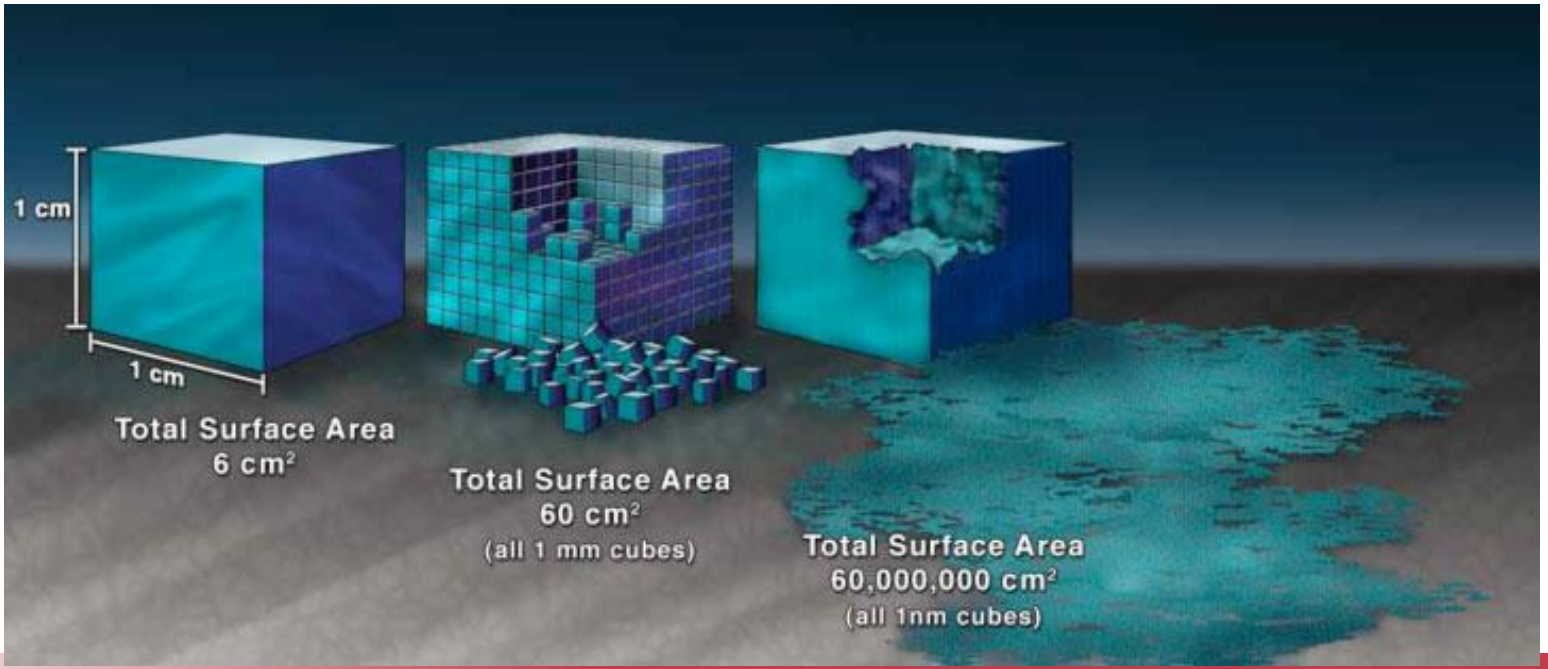


"Nanoscale" ≈ 1-100 nm

Source: DoE

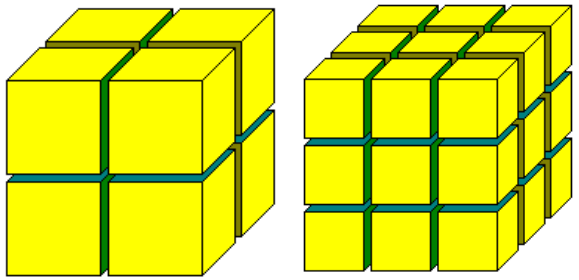
What's special about the nanoscale?

- Scale at which surfaces and interfaces play a large role in materials properties and interactions (high surface to volume ratio; wave properties of light are important; allows for miniaturization)
- Scale at which much of biology occurs
- Scale at which quantum effects dominate properties of materials

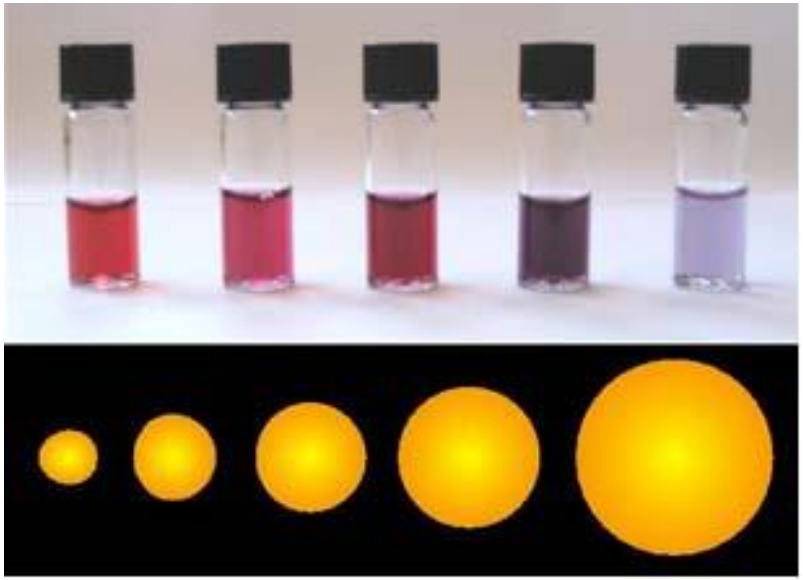


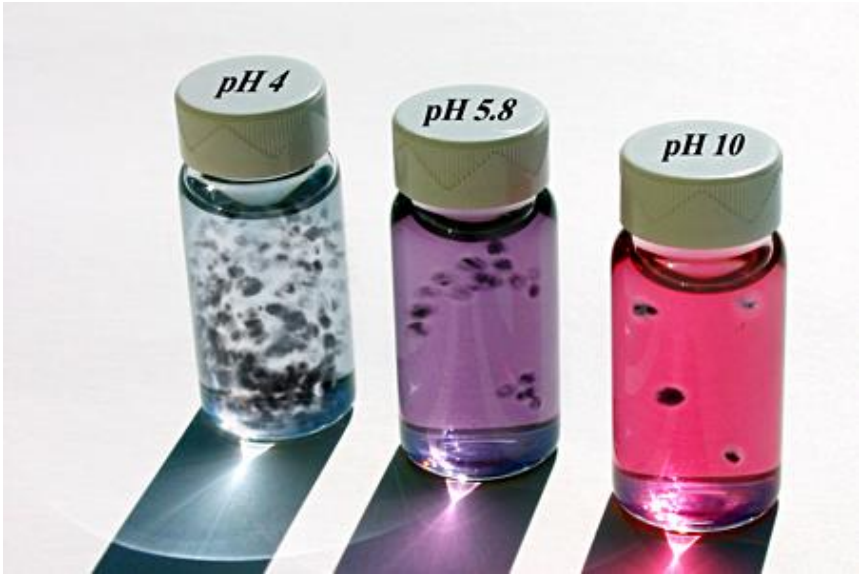
Nanostructure makes things different at the nanoscale

If you keep cutting a cube of gold into smaller and smaller (but bigger than nanoscale) pieces, its color doesn't change.



But when you make gold nanoparticles, the color that we observe at the macroscale changes with size:





Experiment to detect protein unfolding through gold nanoparticle aggregation (Zare lab)

Nanostructure makes things different at the macroscale

Ancient Nanotechnologies

The First Nanotechnologists

Ancient stained-glass makers knew that by putting varying, tiny amounts of gold and silver in the glass, they could produce the red and yellow found in stained-glass windows. Similarly, today's scientists and engineers have found that it takes only small amounts of a nanoparticle, precisely placed, to change a material's physical properties.

Gold particles in glass

Size*: 25 nm
Shape: sphere
Color reflected:

100 nanometers = 0.0001 millimeter

Silver particles in glass

Size*: 100 nm
Shape: sphere
Color reflected:

200 nm

Had medieval artists been able to control the size and shape of the nanoparticles, they would have been able to use the two metals to produce other colors. Examples:

Size*: 50 nm
Shape: sphere
Color reflected:

Size*: 40 nm
Shape: sphere
Color reflected:

Size*: 100 nm
Shape: sphere
Color reflected:

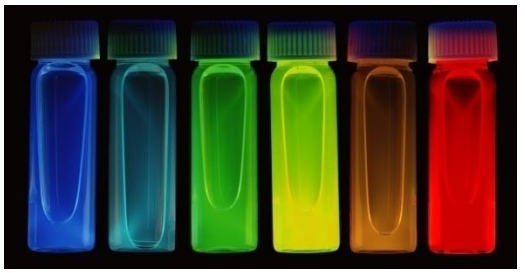
Size*: 100 nm
Shape: prism
Color reflected:

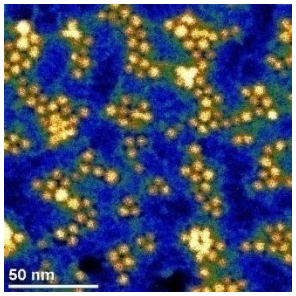
Source: Dr. Chad A. Mirkin, Institute of Nanotechnology, Northwestern University

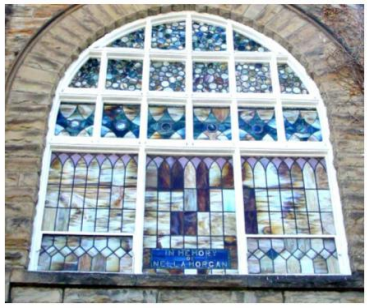
*Approximate

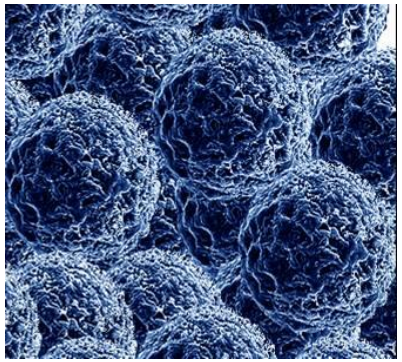
Chad Mirkin, Northwestern University, in NYTimes article by K. Chang - 2005

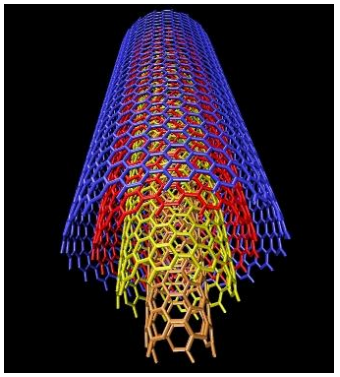
Categories of nanoparticles











Naturally occurring

Man-made by-product

Engineered Nanomaterials (ENM)

The Nano Researchers Toolkit

Fabrication/synthesis

Electron beam writer

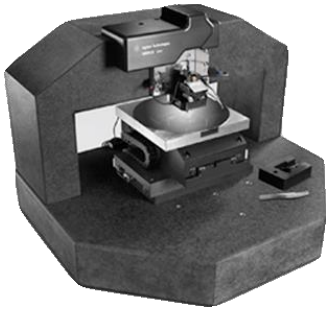
Photolithography

Etcher

Characterization

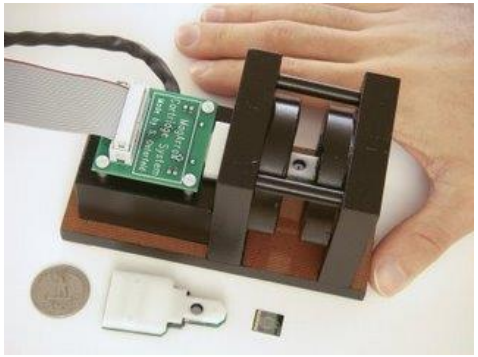
(Seeing at the nanoscale)

Scanning Electron Microscope

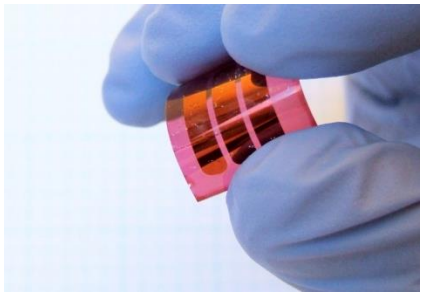


Atomic Force Microscope

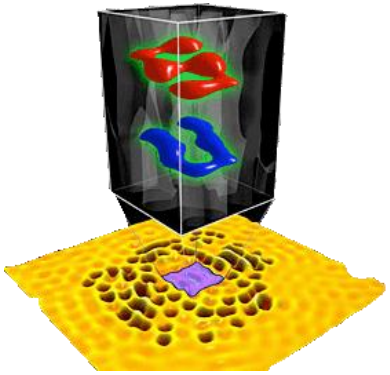
Applications



Cancer detection



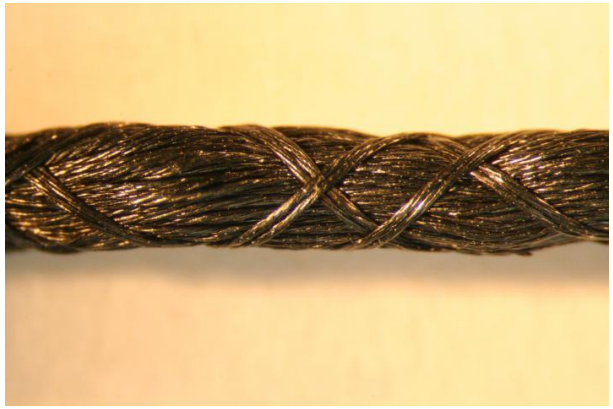
Photovoltaics



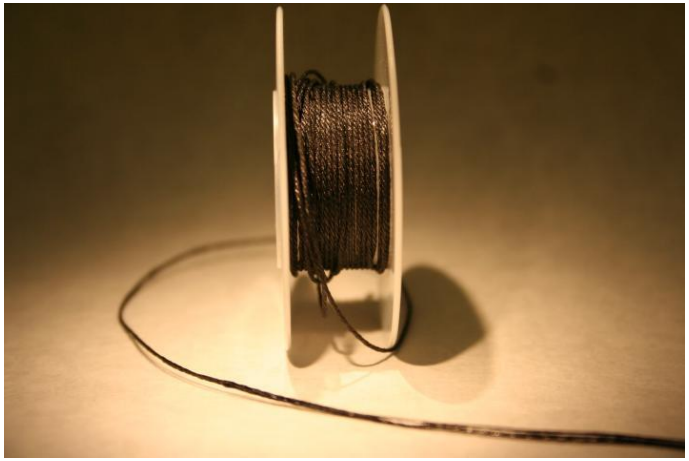
Information Storage

nanomanufacturing

- Chemical vapor deposition
- Molecular beam epitaxy
- Atomic layer epitaxy
- Dip pen lithography
- Nano-imprint lithography
- Roll-to-roll processing
- Self- assembly



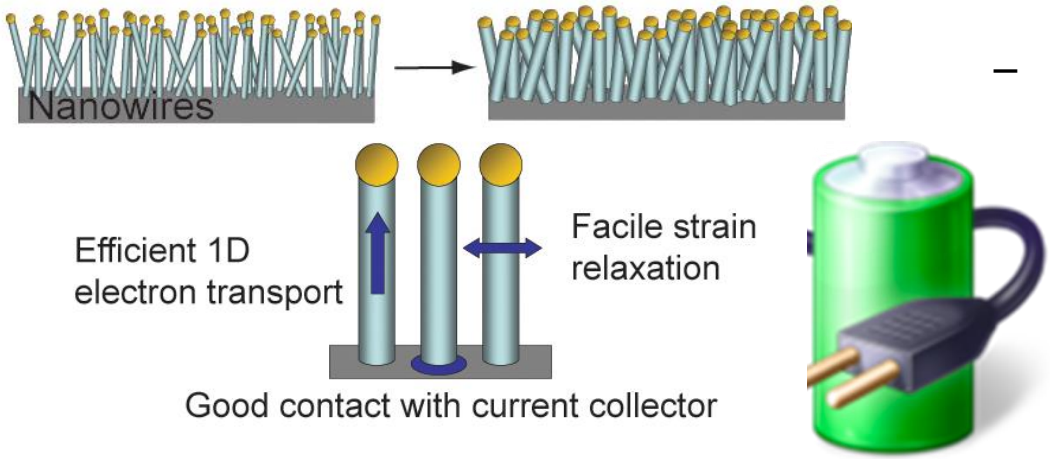
A product of nanomanufacturing: A 16 gauge wire (above), approximately 1.3 millimeters in diameter, made from carbon nanotubes that were spun into thread. And the same wire on a 150 ply spool (below.) Courtesy of Nanocomp



Energy Storage

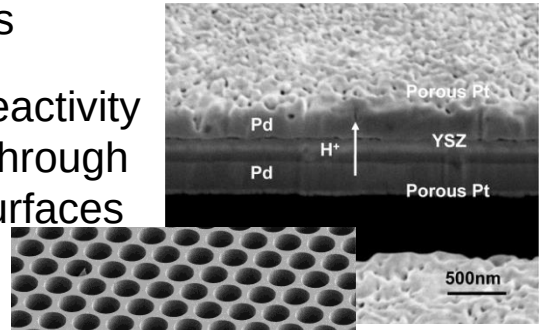
High-capacity batteries

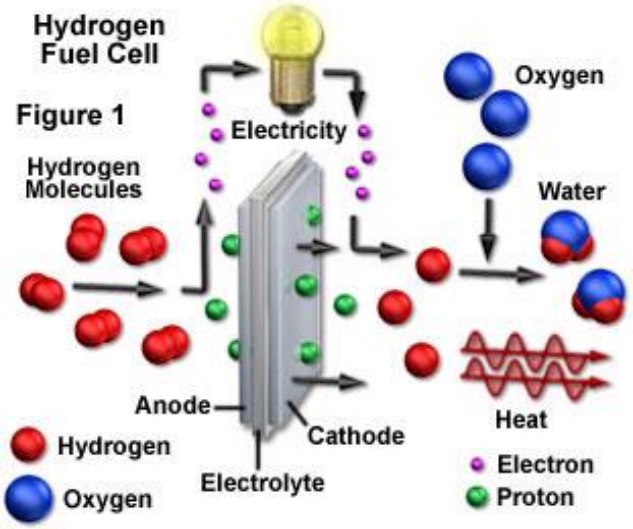
- Use silicon nanowires as anode material to yield 10-fold increase over carbon



High-efficiency fuel cells

- Improvements in membrane fabrication lead to better efficiencies at lower temperatures
- Increasing reactivity of platinum through strain and surfaces



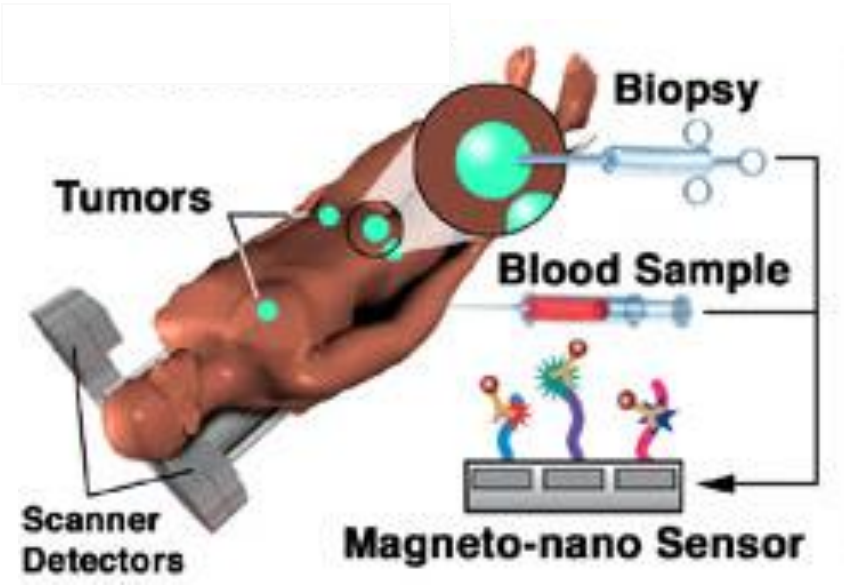


Professors Cui, McIntyre, Haile, Goodwin, Pitsch, Prinz, Goodson, Santiago

Center for Cancer Nanotechnology Excellence Focused on Therapy Response

- Motivation: cancer detection, diagnosis, and treatment

- Technology:
  - In vivo diagnostics: magnetic *nanoparticles* to 'tag' cancer in imaging for treatment and monitoring
  - Targeted drug delivery with *nanoparticles*
  - Ex vivo *nanosensors* to detect cancer in blood sample



Nanotechnology Markets

- Aerospace and defense
- Automotive and transportation
- Information technology and telecommunications
- Energy Production & Distribution
- Medical and pharmaceutical
- Chemicals and advanced materials
- Construction
- Textiles
- Agriculture
- Consumer Products
- Environmental
- Industrial
- Mining and Natural Resources

Current Medical Applications – Commercialized (FDA approved)

- Appetite Control
- Bone Replacement
- Cancer
- Chemical Substitutes
- Cholesterol
- Diagnostic Tests
- Drug Development
- Hormone Therapy
- Imaging
- Immunosuppressant
- Medical Tools

- Over 20 products already commercialized
- Used by researchers involved in drug discovery
- Better imaging techniques
- Prescriptions to treat particular types of illness

http://www.nanotechproject.org/inventories/medicine/apps/

What kinds of nanomaterials (nanoproducts) are currently in commercial production or use?

Mercedes-Benz

Mercedes CLS-class

Wilson Double Core tennis balls

Eddie Bauer Ruston Fit Nano-Care khakis

3M Adper Single Bond Plus dental adhesive

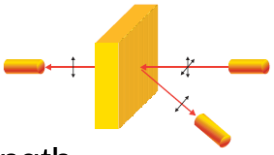
Wyeth Rapamune immuno-suppressant

Smith & Nephew Acticoat 7 antimicrobial wound dressing

Laufen Gallery washbasir with Wondergliss

Samsung Nano SilverSeal Refrigerator

Kodak EasyShare LS633 camera

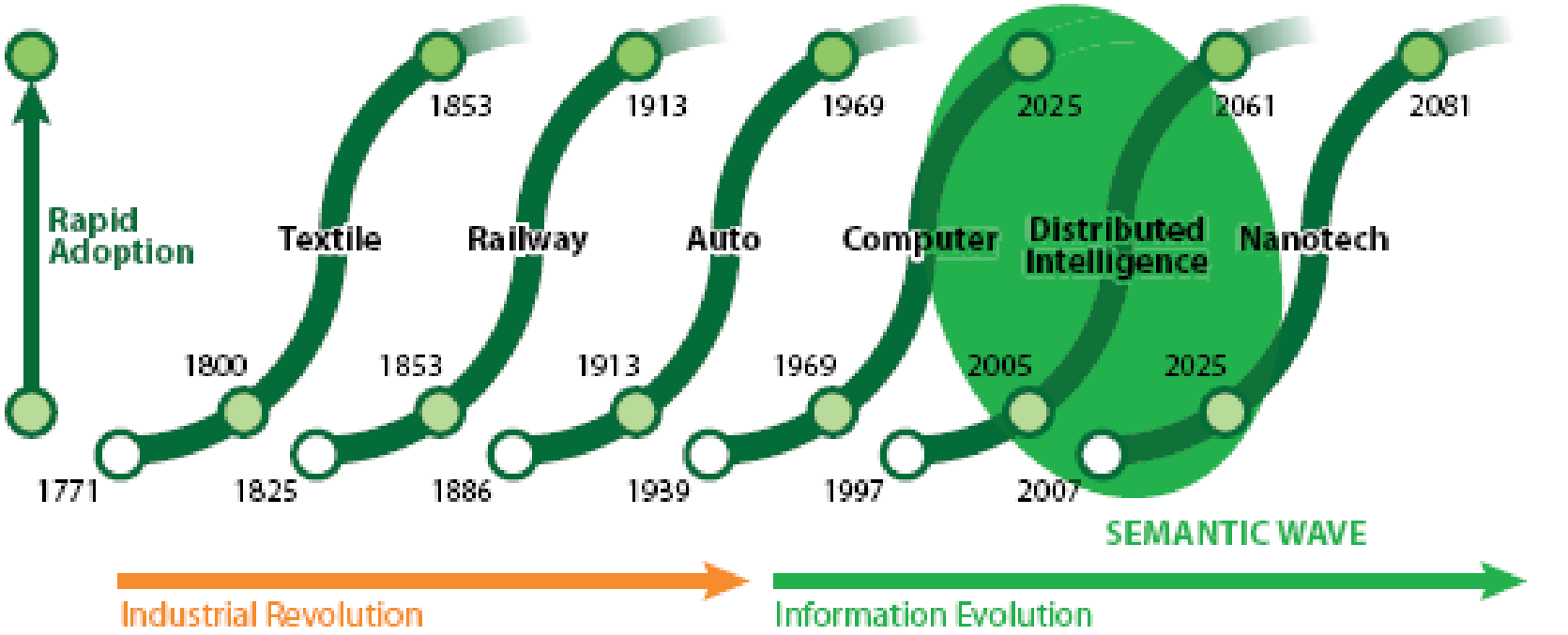


NanoOpto subwavelength polarizing beam splitter/combiner

Hummer H2

Market Size Estimates	(in US$)
Global (US National Science Foundation)	1 trillion by 2015
Global (Lux Research)	2.6 trillion by 2014
India (ReportLinker)	100 million in 2008

Waves of Growth Innovation



Source: Norman Pohr, MainVLynch, based on Joseph Schumpeter

Nanoscale: Benefits and Applications

- Everyday materials and processes
- Electronics and information technology
- Sustainable Energy Applications
- Environmental remediation applications
- Nanobiosystems, medical and health applications
- Future transportation applications

Challenge:

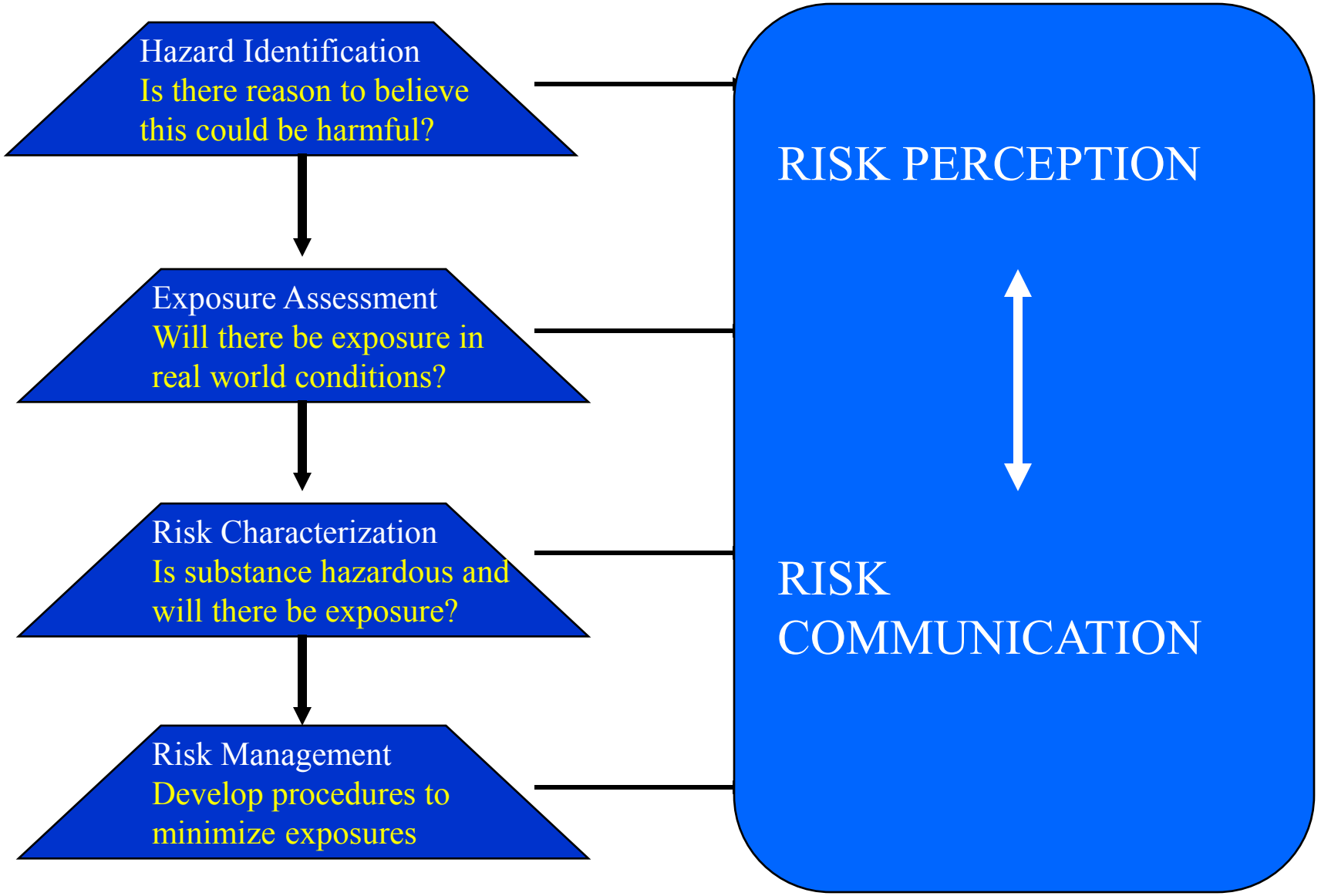
- **Maintaining focus on benefits of nanotechnology via EHS and Ethical, Legal and Societal Implications (ELSI)**

Source: US NNI EHS Research Strategy

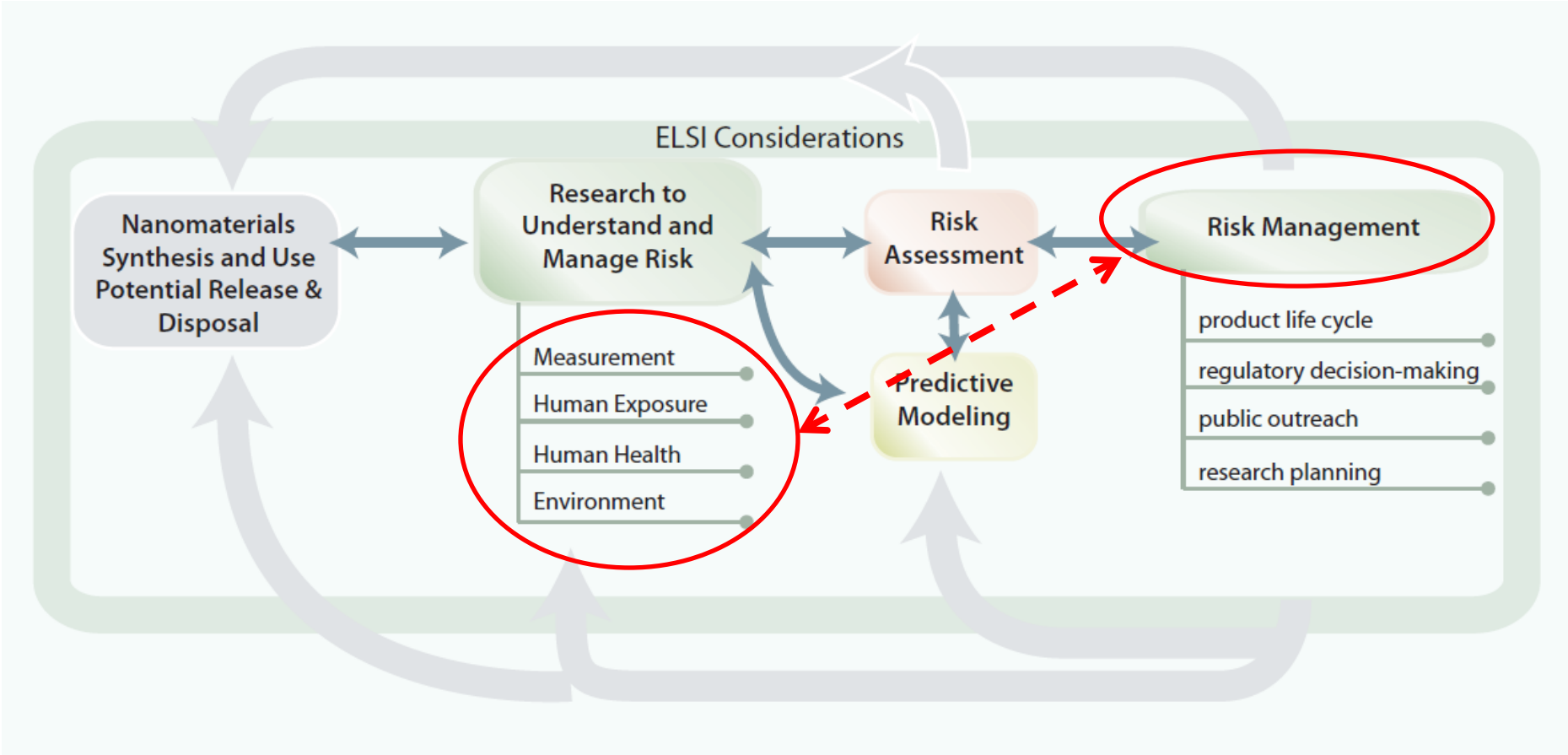
Emerging Technology Risk Management

- Struggle to deal with emergent risks presented by new technologies
- There is no manual for how to address human health risks from increasingly complex technologies
- Stakeholder and citizen engagement is becoming increasingly important
- Uncertainty dominates the decision-making process
- Ill-informed decisions on risks and benefits could be potentially catastrophic

Key Elements of Risk Assessment and Risk Management



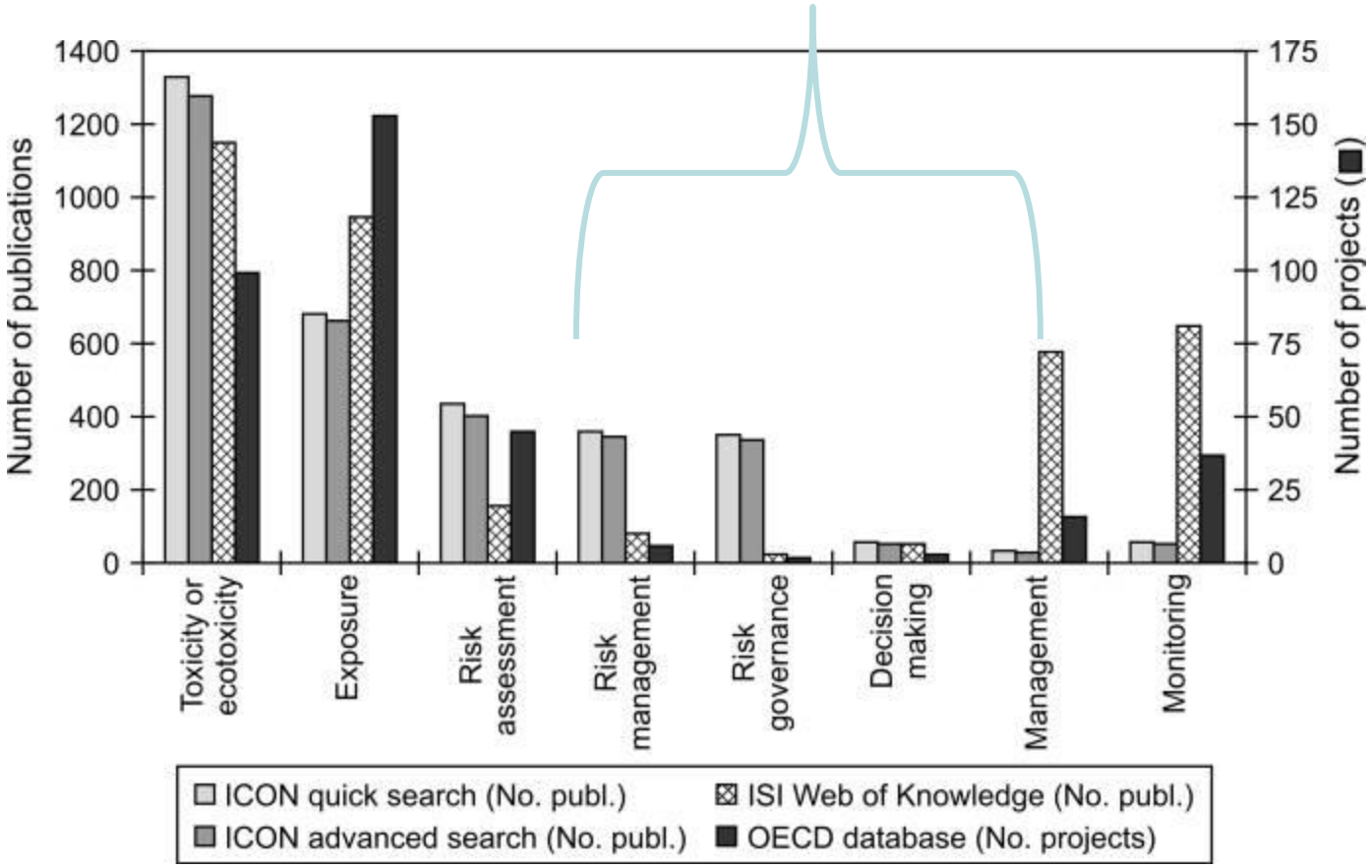
Jumping Ahead in the Risk Management Research Framework



Source: US NNI EHS Research Strategy

NP Risk Management Research

Research is needed in the 'middle ground'.



Grieger, K., Baun, R., Owen, R. 2010. Redefining Risk Research Priorities for Nanomaterials. *Journal of Nanoparticle Research,2(2): 383–392*

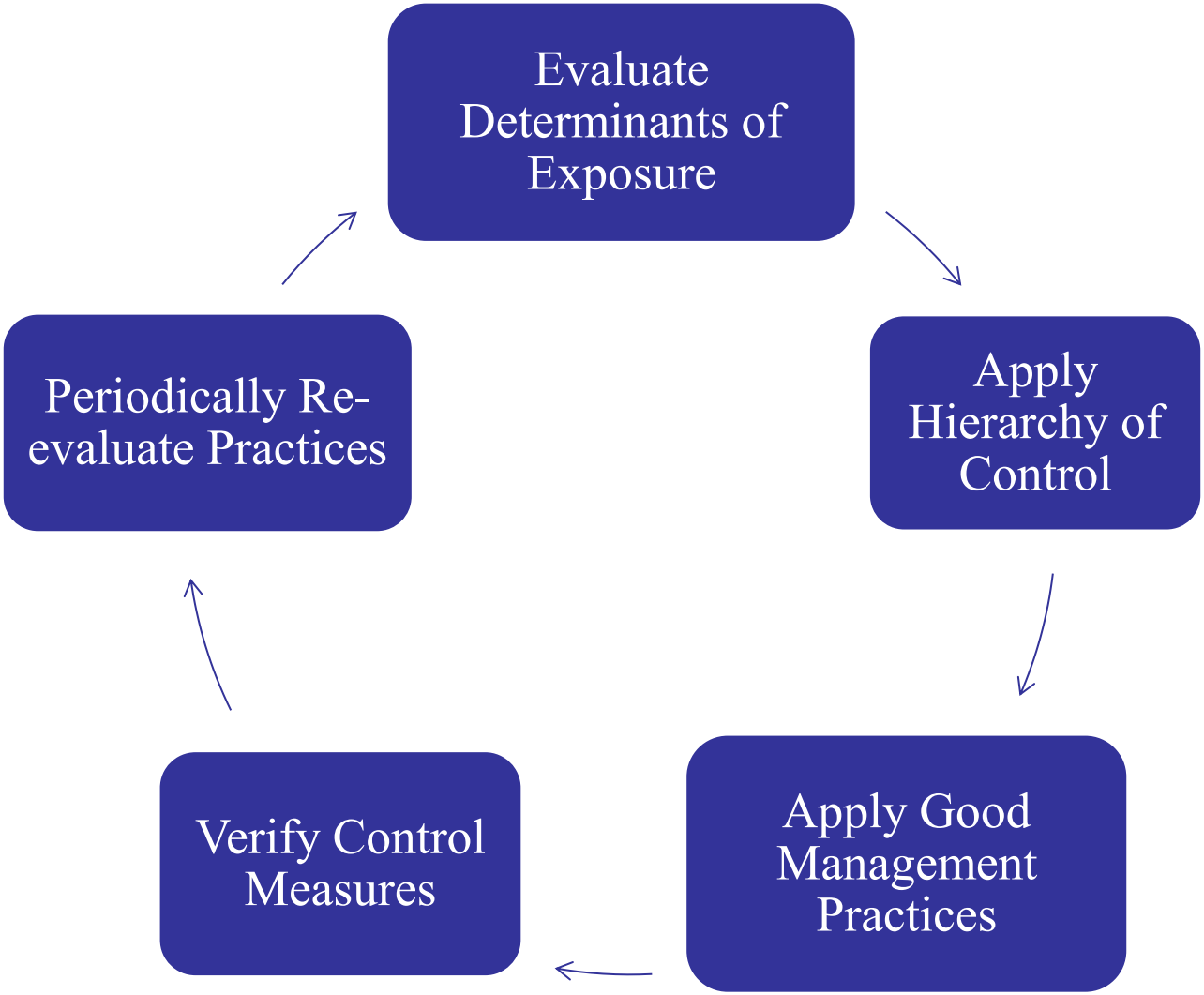
The Motivation for Risk Concerns

- Workers and consumers worldwide are potentially exposed to nanomaterials during production, use or disposition of products
- Few occupational exposure limits (OELs) have been developed for specific nanomaterials
- Adequacy of existing OELs is often not known
- A prospective risk management approach builds in safeguards in the absence of data and allows the technology to advance

Qualitative Risk Management

- Decision-making without all of the information necessary for quantitative risk assessment
- Draw from:
  - **Established practice**
  - **Analogous materials and situations**
  - **Expert experience and knowledge**
- Develop as:
  - **Good practices for working with engineered nanomaterials**
  - **Use of risk based approaches (e.g., control banding; ALARA, etc.)**
  - **Identify new risk management approaches**
  - **Utilization of existing exposure control techniques**

ENM Risk Management Plan



Nanomaterial Exposure Assessment

- Critical component of risk management
- Identifies populations at risk
- Characterize the exposure, therefore better understanding of risk
  - Nature of exposure: low v. high; short v. long
  - Extent of exposure: few or many
  - Complexity of the exposure
  - Place the exposure on the life cycle
- Verify controls

Exposure assessment: a combination of

- **Online Monitoring: Instrumental approach**
  - Number concentration
  - Surface area
  - Size-distribution (number, mass)
  - Mass-concentration size-fractioned
  - Specific monitor (e.g., black carbon monitor)
- **Off-line analysis: Integrated sampling approach**
  - Electron microscopy
  - X-ray diffraction analysis
  - Elemental analysis

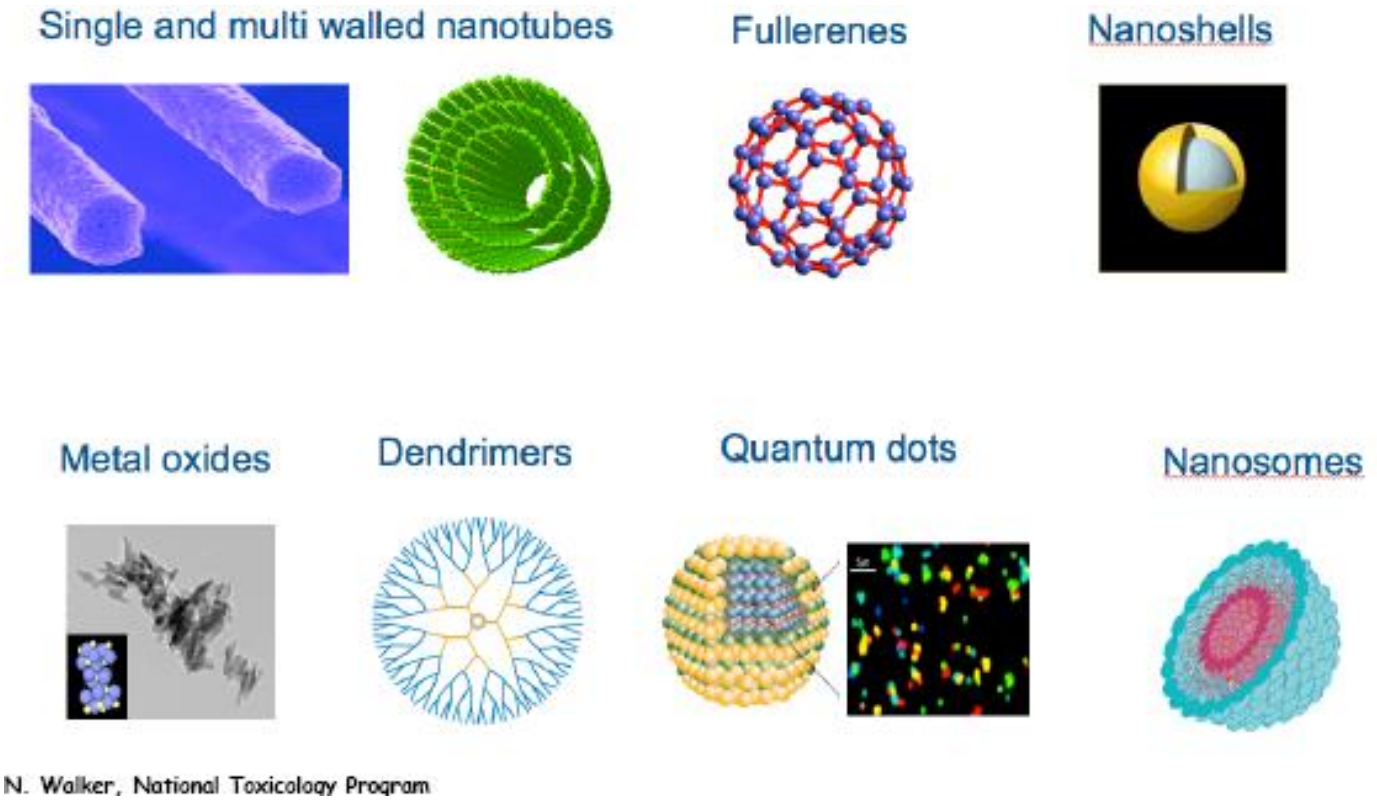
“Nanoparticle” Exposure Assessment Challenges

- Definition of nanoparticle or nanomaterial
- Heterogeneity of nanomaterials
- Agreement on the most appropriate metric
- Lack of evaluation criteria
- Lack of ruggedized exposure evaluation methods

Nanoparticle Forms

- Considerations apply principally to engineered nanoparticles!
- Working with nanoparticles in a slurry is less likely to present an inhalation hazard than powders
  - Caution: Getting nanoparticles into a slurry or a composite can present hazards!
- Nanoparticles in a composite material are hard to get out of that form

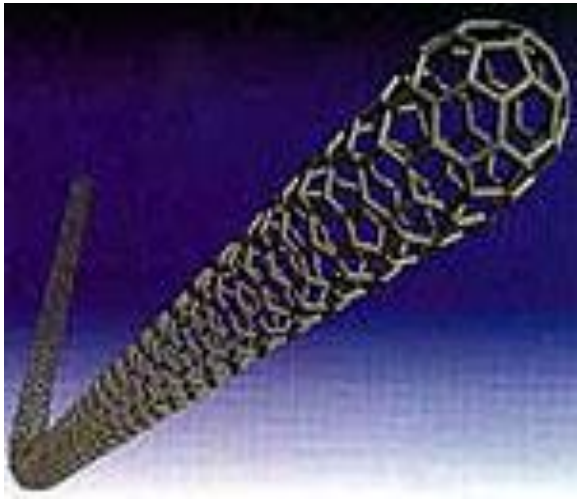
Nanoparticles: Many shapes, many chemistries



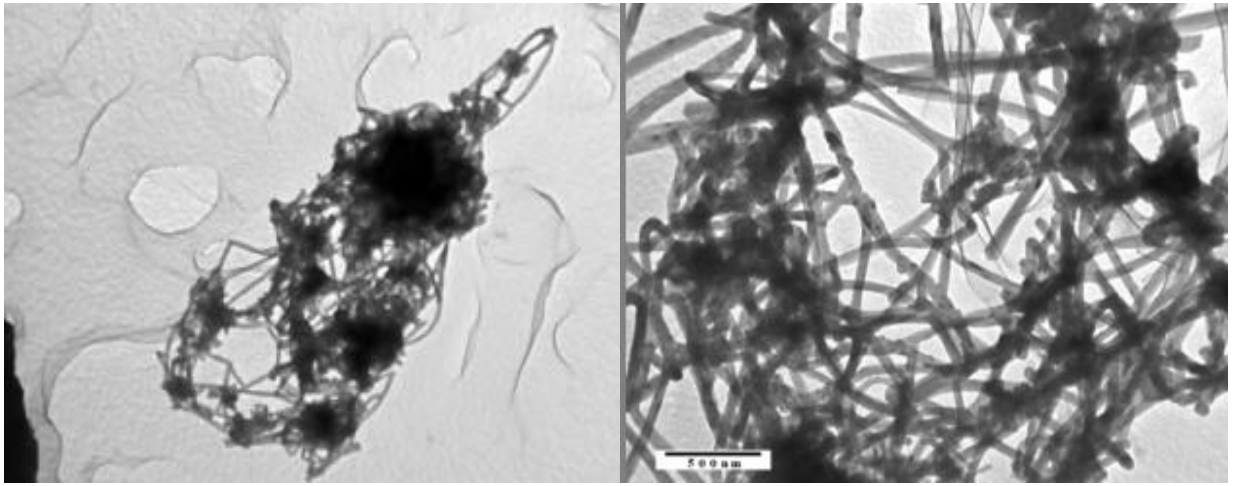
Not all nanoparticles are the same

The reality of airborne nanomaterials

Artist's rendering versus real world



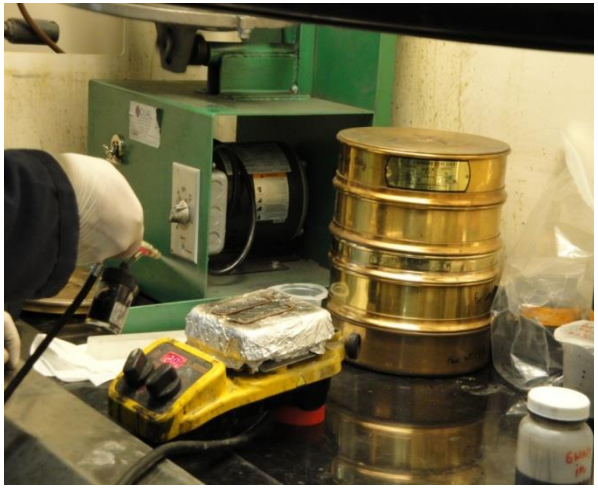
Single-walled CNT



MWCNT air samples

Changing Nanotechnology Workforce

- Trend – from laboratory research to scale-up
- Higher potential exposures



- "Nanotechnology is unquestionably moving toward manufacturing, involving a still very small but increasing component of the labor force." [Invernizzi N. J Nanopart Res 2011]

Exposure Data: Summary and Challenges

- New thinking and strategy needed
- Exposures do occur in the workplace
- Exposure limits are being developed
- Mass is still the primary metric reported in hazard studies
- Direct-reading approaches have a place
- Additional metrics need to be explored: fiber count?
- Confirmatory methods are needed
- Controls can be effective

Control of Nanoparticles

Exposure by inhalation

Install similar engineering controls used to control gases, vapors and small aerosols:

-Enclosures

-Local exhaust ventilation

-Fume hoods

-General ventilation

-On-gun extraction in welding

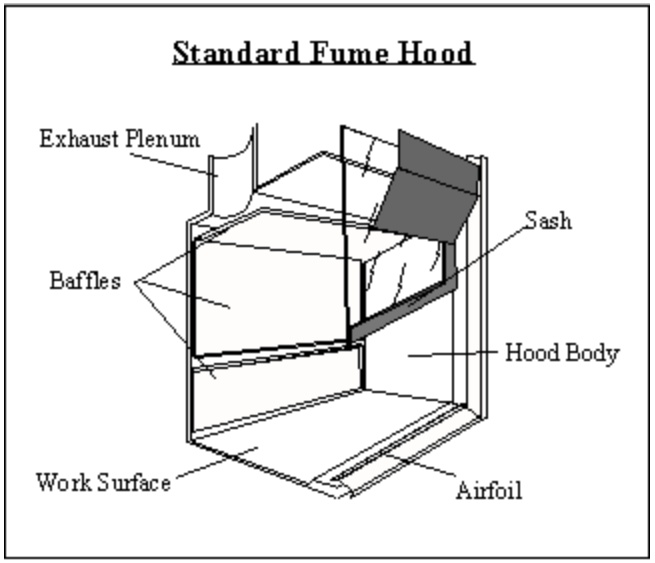


Figure 1 Basic features of a standard fume hood.

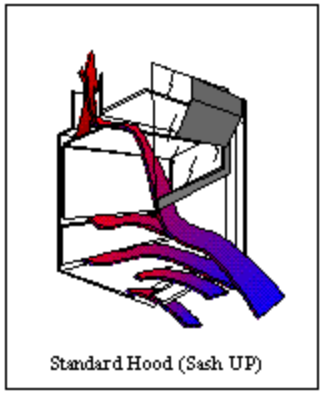
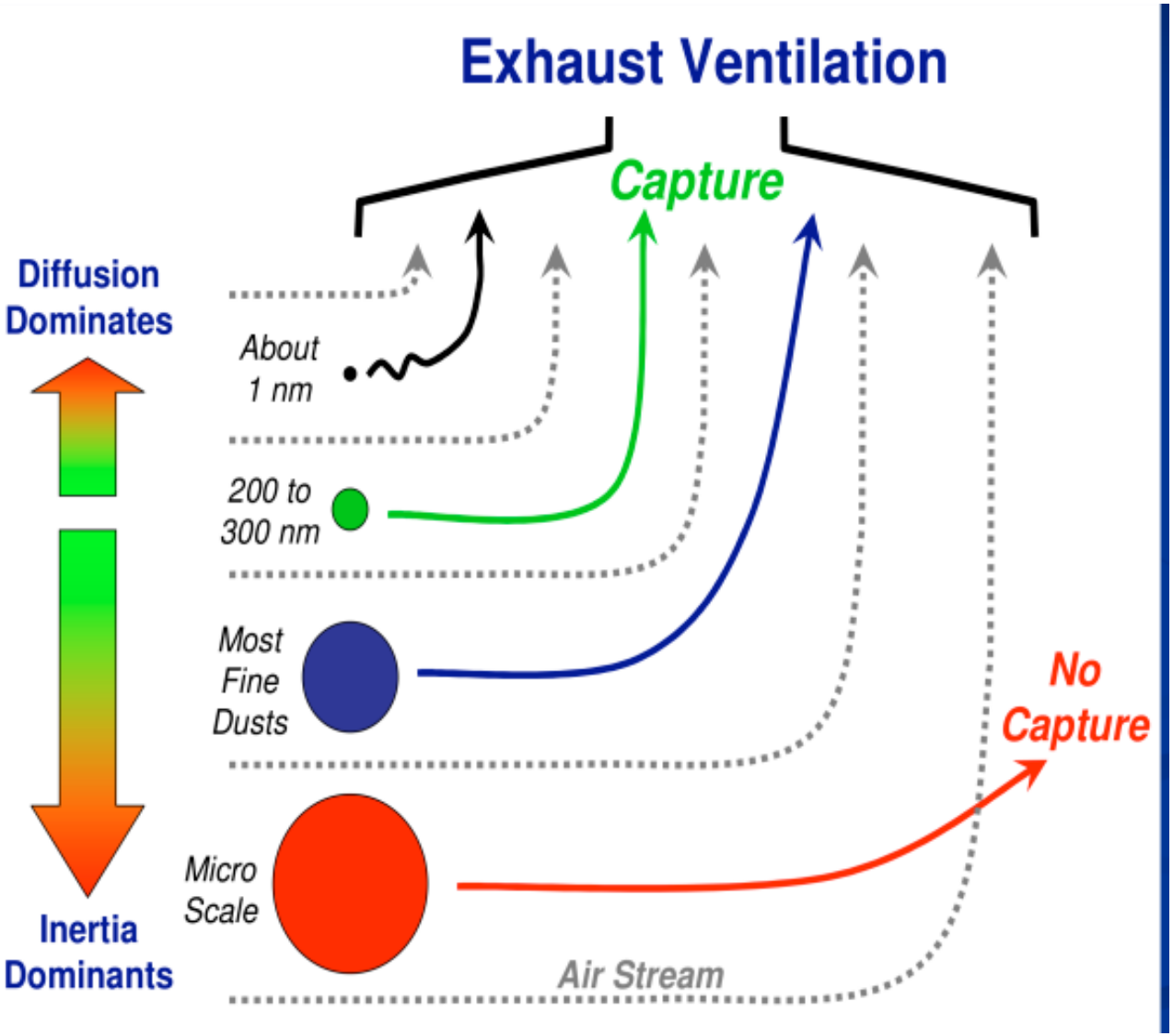


Figure 3 Standard hood flow path.

Local Exhaust Ventilation - Exterior Hood Concepts



From: NIOSH, *Approaches to Safe Nanotechnology* (2009)

Evaluate Effectiveness of Controls

Case Study: Use of LEV during reactor cleanout

Average percent reduction from the use of a local exhaust ventilation unit:

96 +/- 6% based on particle counts

88 +/- 12% based on mass

Mark Methner, PhD, CIH; JOEH June 2008

Effectiveness of PPE and Engineering Controls

- Engineering controls and PPE do minimize workplace exposures, but additional research is still needed to fully understand the limitations
- Filters behave as expected - there is no deviation from classical single-fiber theory for particulates as small as 3 nm in diameter
- It is likely that NIOSH approved APRs when used in a complete respirator program will be useful for protecting workers from nanoparticle inhalation and should provide levels of protection consistent with their OSHA assigned protection factor (APF)
- Research on effectiveness of protective clothing and gloves is just beginning
- Nanotechnology can be used to improve control technologies

Don’t forget other nanofabrication hazards

- Toxic gases and chemicals
- High temperatures >600^{o}C
- High pressures
- Lasers
- Strong magnetic fields

Wisdom Applied to Emerging Technologies

"To know that we know what we know, and that we do not know what we do not know, that is true knowledge"

(Confucius)

Nanomaterials in the Workplace

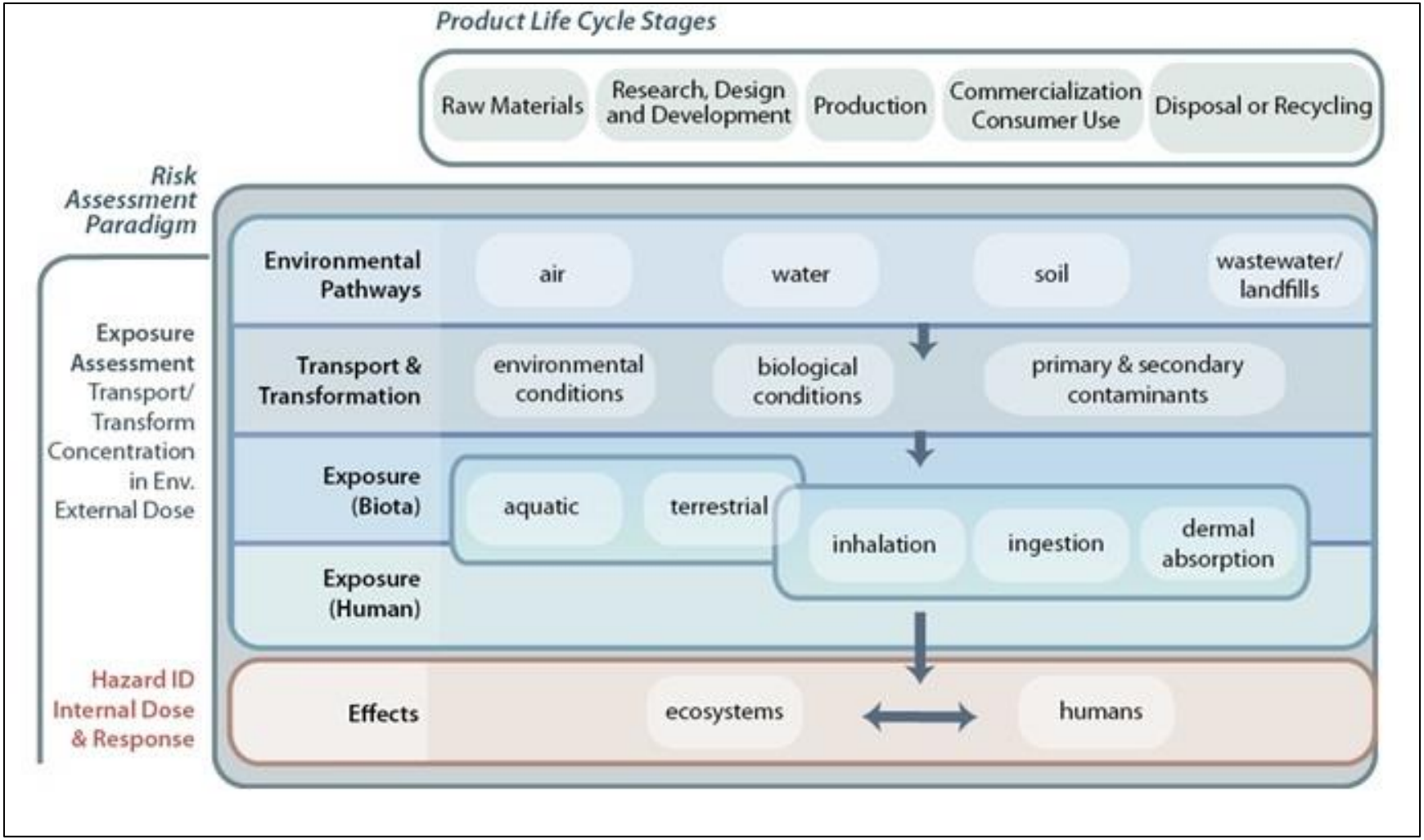
What we know

- Some potential hazard
- Some risk may exist
- Some exposure occurs
- Nanoparticles can be measured
- Nanoparticles can be controlled
- Filters and respirators should protect
- There are no specific exposure limits
- No specific medical tests, but hazard surveillance is prudent

What we don't know

- Nature and extent of hazard?
- Nature and extent of risk?
- Nature and extent of exposure?
- What measures to use?
- Limitations of controls?
- Limitations of protection?
- What limits are appropriate?
- Content of surveillance?

Nano Risk Management Across the Life-cycle



The risk assessment paradigm (*on left*) integrated with nanomaterial life cycle stages (*across top*). (Design credit: N.R. Fuller of Sayo-Art.)

NNI Nanotechnology EHS Research Strategy – guidance to federal agencies

Ethical, Societal and Legal Issues (ESLI)

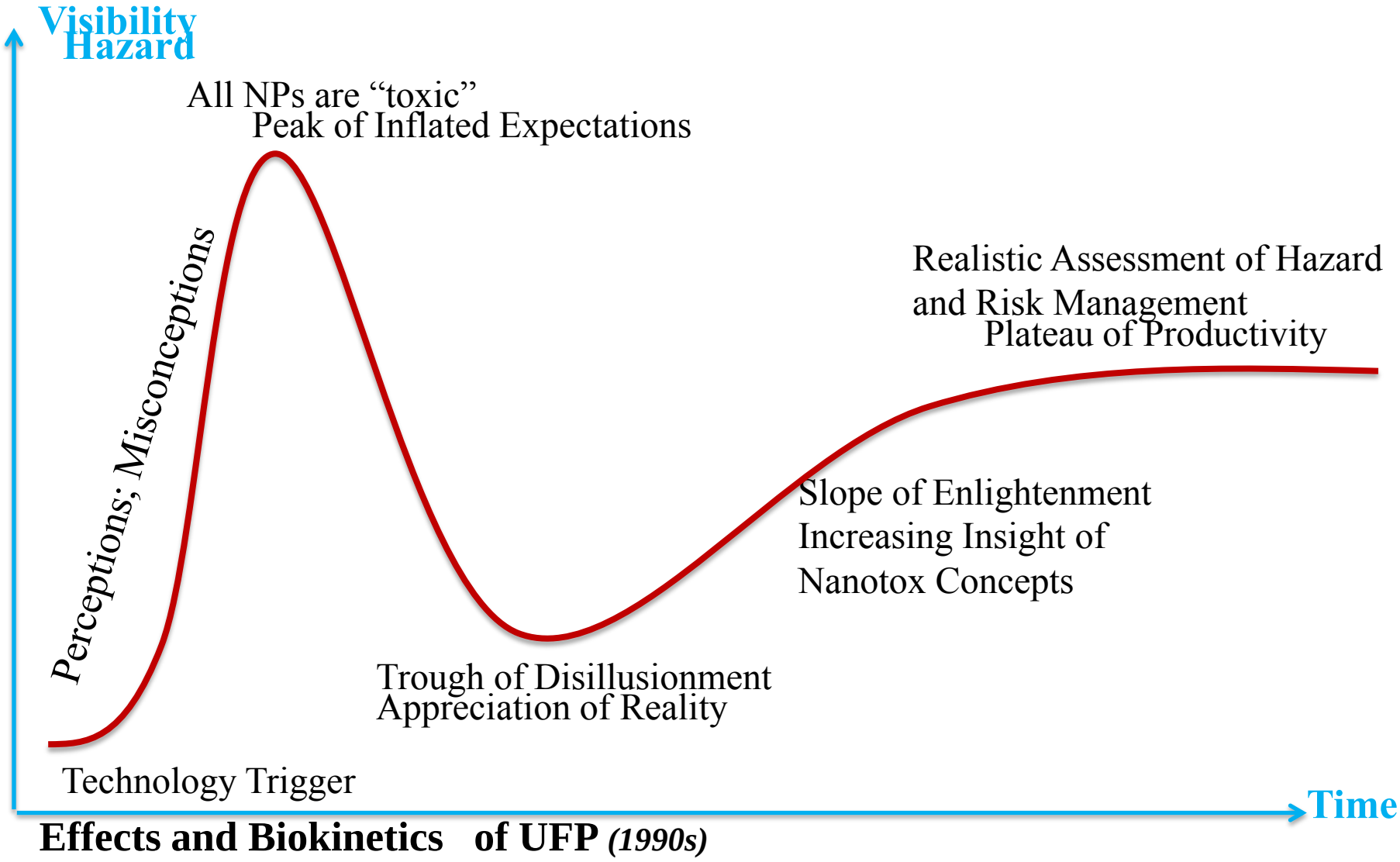
- How nanotechnology research and applications are introduced into society;
- How transparent is decision making;
- How sensitive and responsive policies are to the needs and perceptions of the full range of stakeholders;
- How ethical, social and legal issues are addressed will determine public trust and the future of innovation driven by nanotechnology

Key Governance Principles

- Regulatory response should be coordinated
- Regulatory approaches should be flexible and adaptive
- Design information gathering initiatives with endpoint in mind
- Lifecycle approach to risk management
- Balance and proportionality between costs and benefits of regulating
- Clarify accountability and ensure transparency in regulatory system

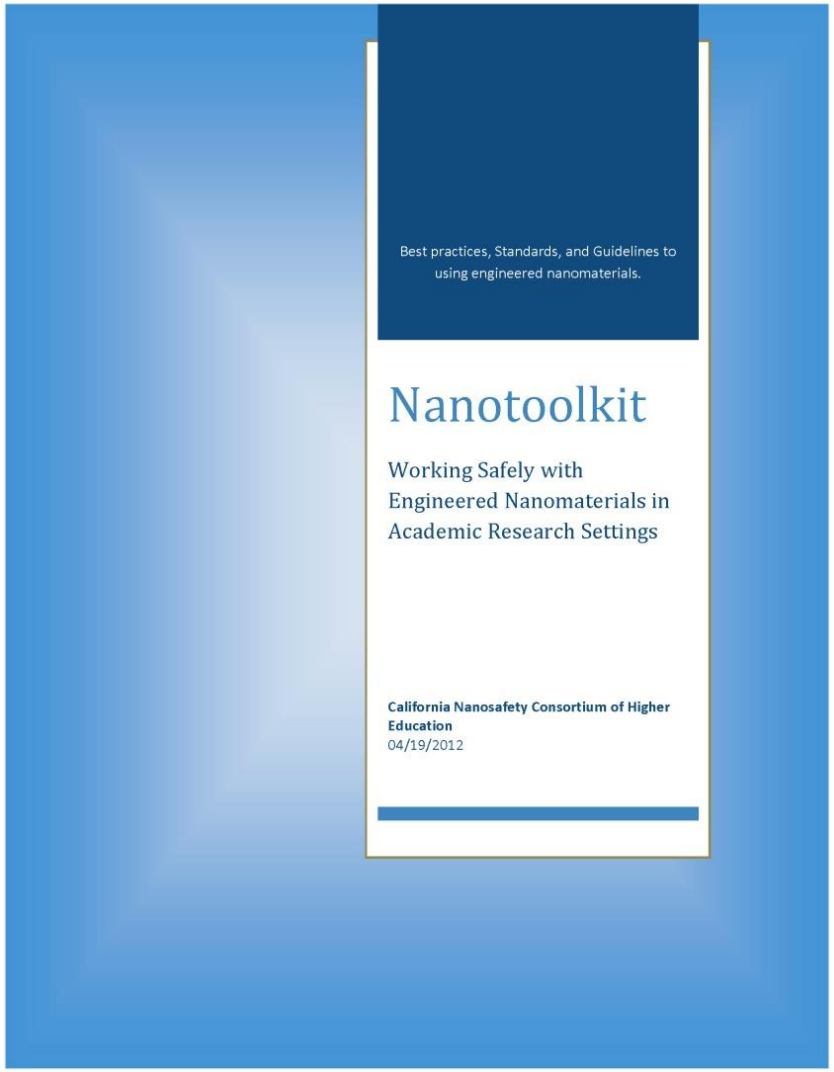
J Pelley and M Saner, International Approaches to the Regulatory Governance of Nanotechnology, 2009

Nanotoxicology – Hype Correlation
Emerging Technology Hype-Cycle Phases



http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp

The NanoToolkit



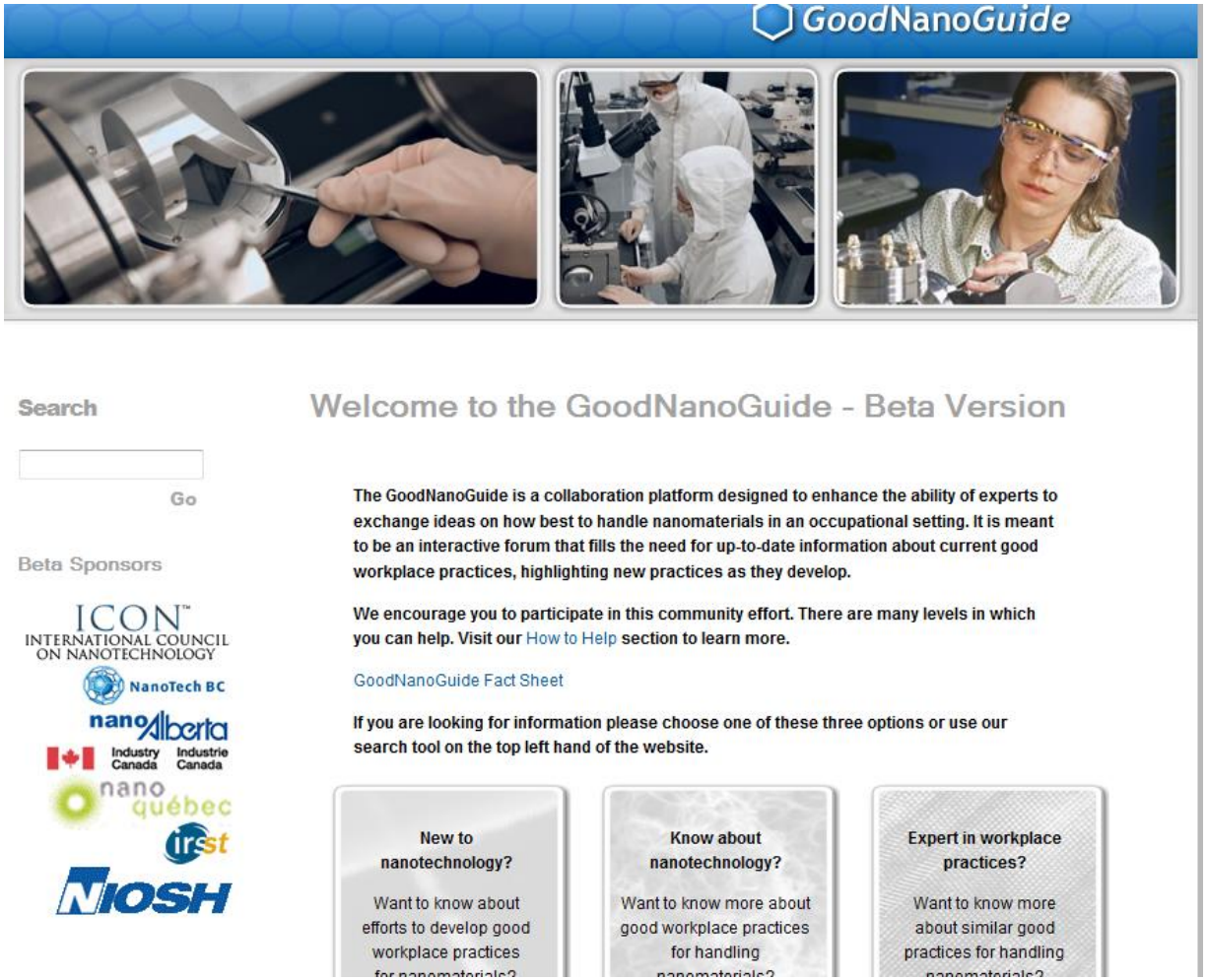
The NanoToolkit – A Functional Operations Safety Guide for Academic Researchers

developed by

The California Higher Education Nanosafety Consortium

http://www.goodnanoguide.org/Research+Facility+Protocols

Sharing Experience and Knowledge



Risk Management Recommendations

- **Toxicological profiling** needed for priority NPOCs: predictive profiling studies on important NM classes & hybrids
- **Risk Assessment of NPOCs**: for chemical and physical properties, processes and ALL parts of life cycle – More use of 3rd party due diligence for RA/RM (e.g., nanoTox, inc.)
- **Workplace controls**: move to higher order controls for scale-up from R&D to manufacturing phases; use 'control banding'
  - Hierarchy of controls: elimination, substitution, enclosure & engineering controls, administrative controls, personal protective equipment (PPE)
- **Develop appropriate monitoring**: (if feasible) to assess controls; but techniques not widely available yet
  - **Two stage process**:

  a) Adopt ***Precautionary Principle*** when exposure std is unknown

  b) Adopt ***As Low As Reasonably Practicable*** (ALARP) approach when exposure standard is known

Summary

- Nanotechnology risks encompass not only possible actual risk associated with nanomaterials, but also the public perception of the technology/products
- At the operational level, application of risk based controls can be effective at reducing possible unknown risks of unbound engineered nanomaterials.
- Government regulation is currently under development consideration – will be challenging given lack of risk assessment information
- Potential exists for nanotechnology development to be curtailed by inordinate regulations, adverse public perception, and lack of openness by the nano-community to share risk information and knowledge
- Future for nanotechnology is very bright and we are on the cusp of a new economic driver for the next 50 years, so long as the technology continues to be responsibly developed with risk information shared.