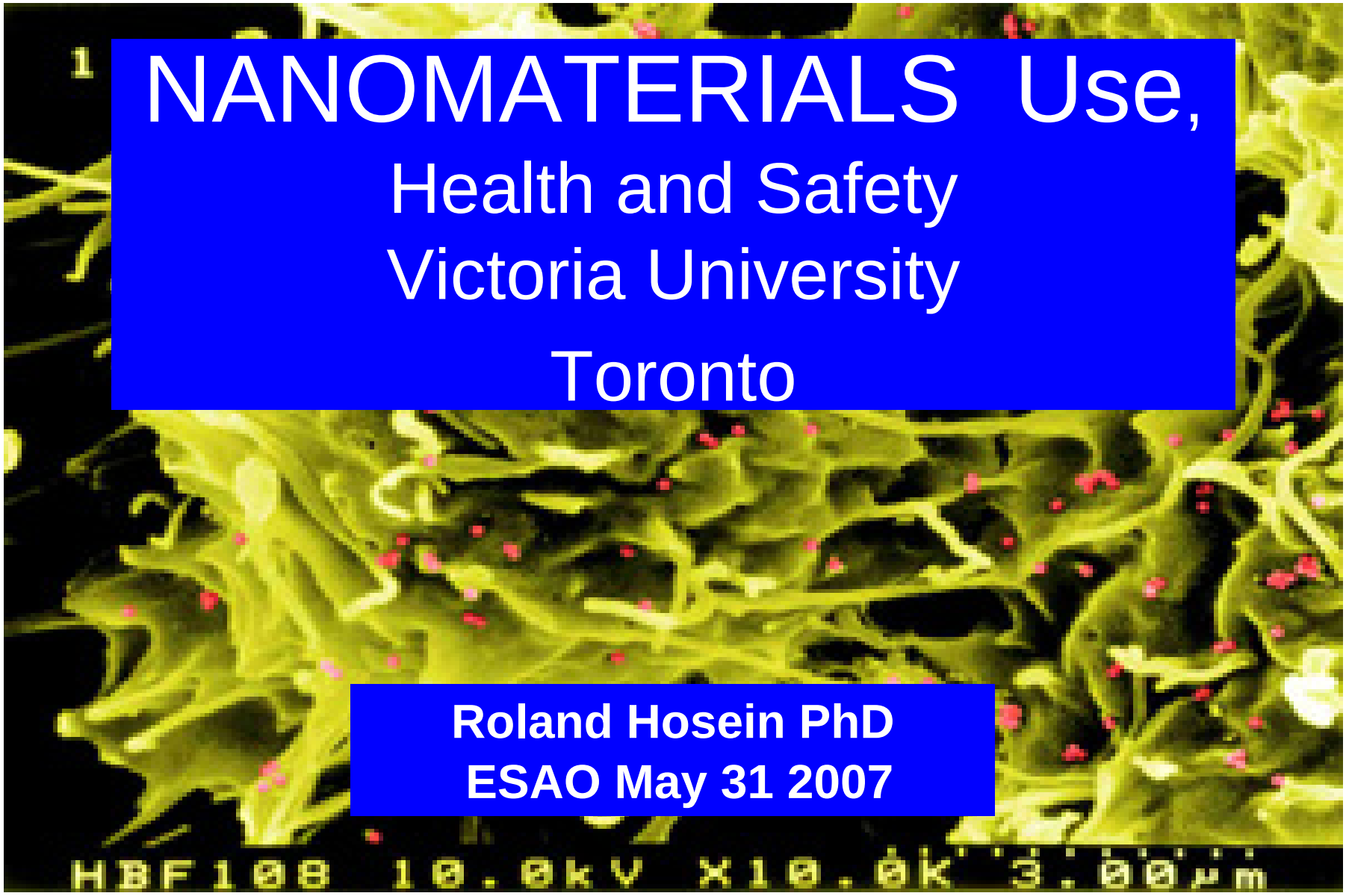

NANOMATERIALS Use,

Health and Safety

Victoria University

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ESAO May 31 2007

Scanning electron micrograph of a **macrophage** (RAW 264.7) phagocytes ultra fine hematite particles. (picture taken by H. Zöltzer, Universität Kassel)

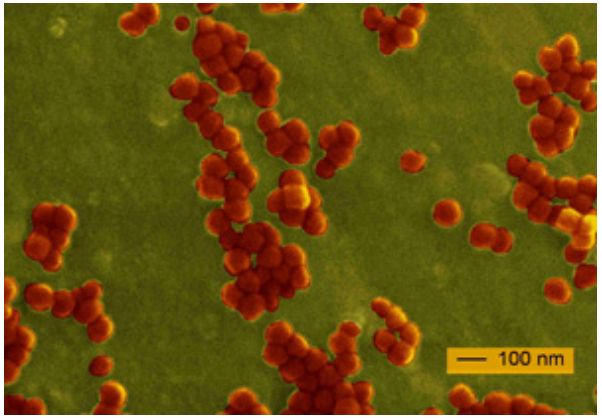
Overview

- ✓ Overview of nanomaterials
  - Why the focus on nano?
  - Significance of the nanoscale
  - Current and potential uses
- ✓ Health and Safety Aspects
  - Influencing factors
  - Modes of exposure
- ✓ Workplace challenges
- ✓ Analysis methods
- ✓ Controls
- ✓ Issues and concerns
- ✓ Issues for Educators

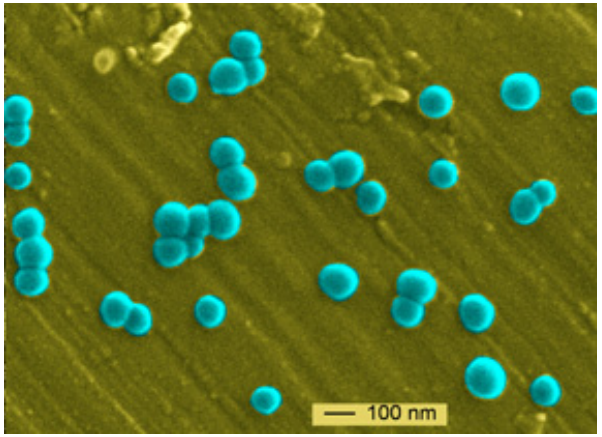
Why the focus on nano?

- ✓ “Nanomaterials” – at least one dimension < 100nm
  (Nanoparticle – diameter < 100nm)
- ✓ Recent technology has allowed field to grow
  - Sophisticated tools have been developed to investigate and manipulate matter on nanoscale
    - Scanning Tunneling Microscope (1982)
    - Atomic Force Microscope (1986)
    - Transmission Electron Microscopy
    - Probes that can pick up, slide or drag atoms around to create nanostructures
- ✓ Can manipulate structures for novel applications
- ✓ From 1997 to 2006, US government investment in nano-development rose from $400 million/year to under $3 billion/year ; Canada about $300MM total so far

Nanoparticles < 100nm diameter



Scanning electron micrograph of **hematite** (a-Fe_2O_3, ~ 70 nm). (synthetically produced by W. Ferstl, ITC-WGT)



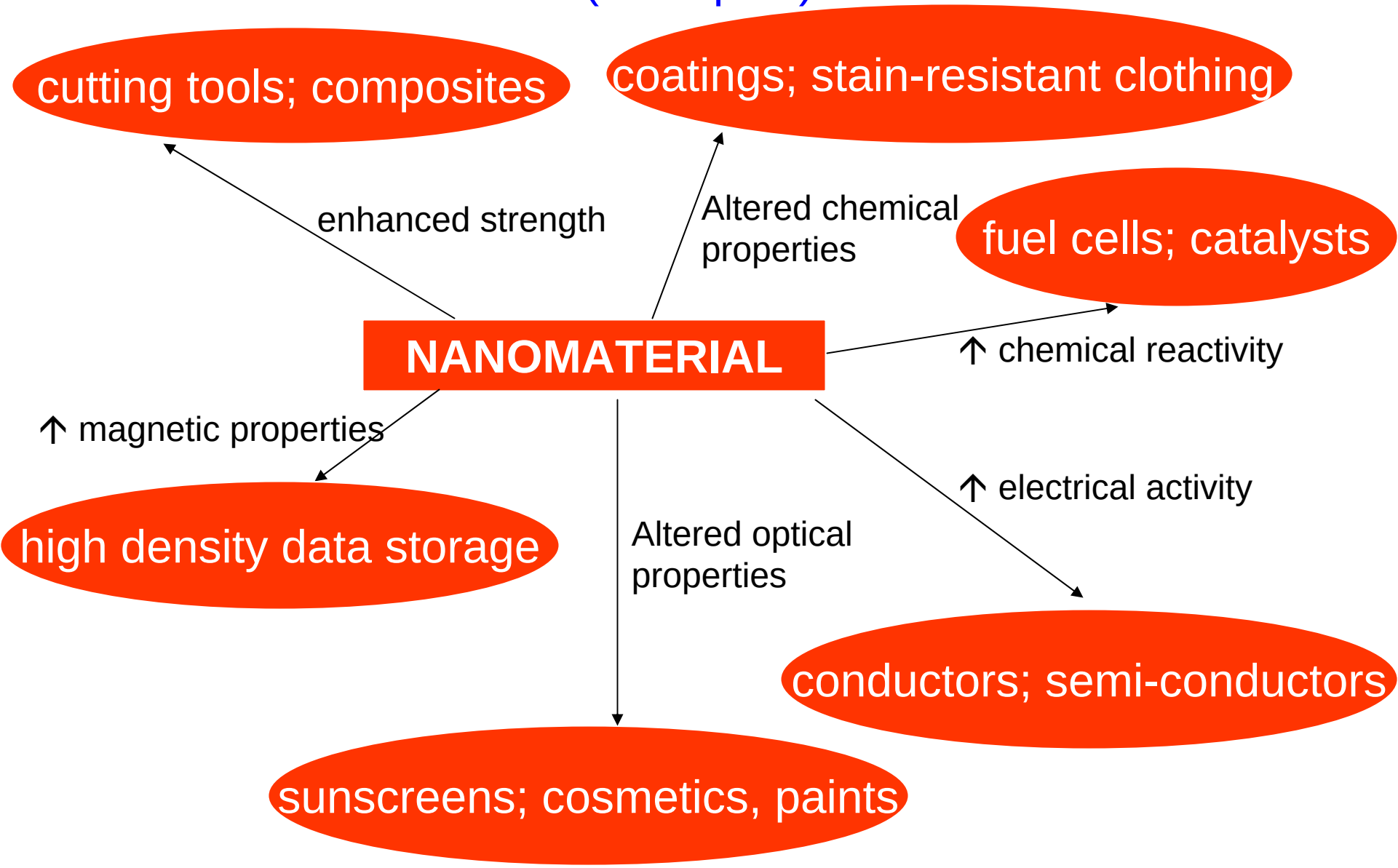
Scanning electron micrograph of **silicasol** (amorph SiO_2, ~ 60 nm). (synthetically produced by W. Ferstl, ITC-WGT)

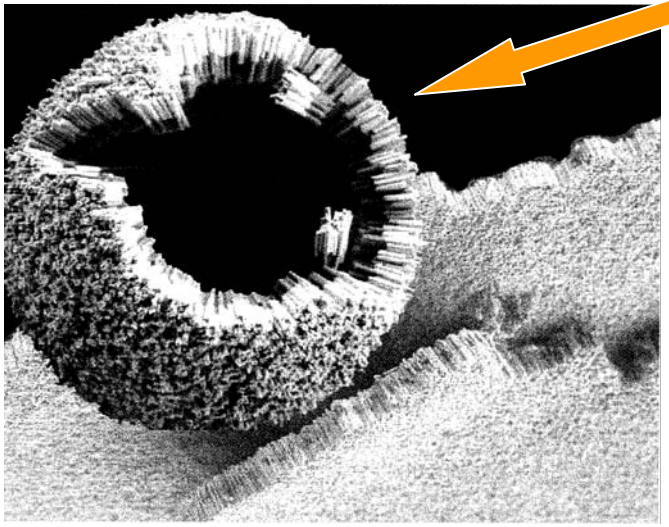
- Significance of <100nm
  - Engineered NP's seem to display different properties when composed of nano-ultrafine particles rather than larger particles
    - Nanomaterials have an increased relative surface area than same mass of material in larger form
      - Can increase materials chemical reactivity
      - Can change strength and electrical properties
    - Quantum effects dominate the behaviour of matter at the nanoscale
      - Can change materials' optical, magnetic or electrical properties

Can exploit effects to create structures, devices, & systems with novel characteristics, functions, & applications

Linking benefits to possible applications

(examples)





Self-assembly of gold nanorods in a curved structure

Current Applications

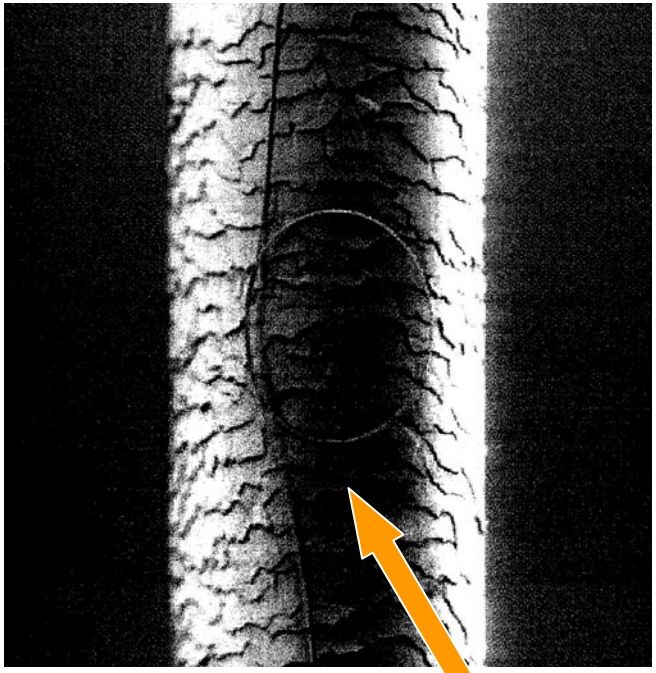
- Skincare
  - Sunscreens, cosmetics (metal oxides)
- Structural
  - Composites, Coatings, Thin films, Powders, Metals, Catalysts (sporting goods, stain-resistant clothing, tires, paints, semi-conductors, fuel cells)

Research Uses

- Environmental
  - Remediation (dendrimers), nanomembranes
- Biotechnology
  - Drug delivery (quantum dots), biosensors
- Integrated Circuit Technology (ICT)
  - Single wall nanotubes, nanoelectronics, opto-electro materials, organic light emitting diodes

Future Uses

- Medical implants; Military battle suits; self healing repair
- Water purification; Magnetic materials;agri chemicals
- Cancer treatments; Embedded Sensors; smart drugs
- as thousands of interacting components



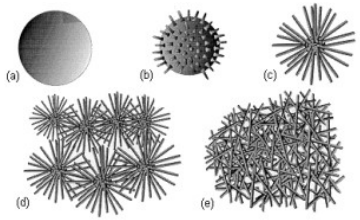
Nanowire on human hair

Products just arriving or anticipated: Bio-medical

- Brain–machine interfaces;
- Chips replacing the memory part of the brain
- Bionic implants: bionic ears, eyes, legs and arms, knees, joints, kidney, liver, lungs, discs, muscles, artificial nose and tongue functions;
- Neural and spinal cord prostheses;
- Artificial womb;
- Newly designed life-forms (synthetic biology);
- Enhanced animals,
- Stem cell technology (embryonic, umbilicord, placenta and adult derived) used for numerous purposes
- Nano-formulated drugs, drug delivery systems, herbs,….
- Longevity immortality products,
- Star trek style food replicator (molecular manufacturing)

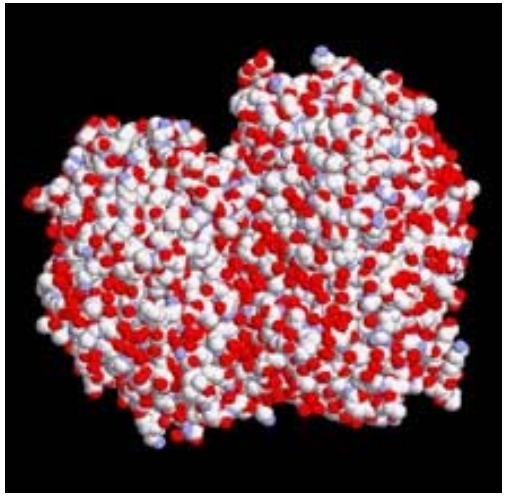
Health effects - factors

- With over 300 nano-enhanced products, already millions of workers involved in R&D, manufacturing, integration and transporting of nano-materials
- Risk greater when particle in free form (not fixed in a structure)
- Determinants of toxicity (From quartz, asbestos, air pollution studies)



1) Physical dimensions of particles - affect penetration and durability

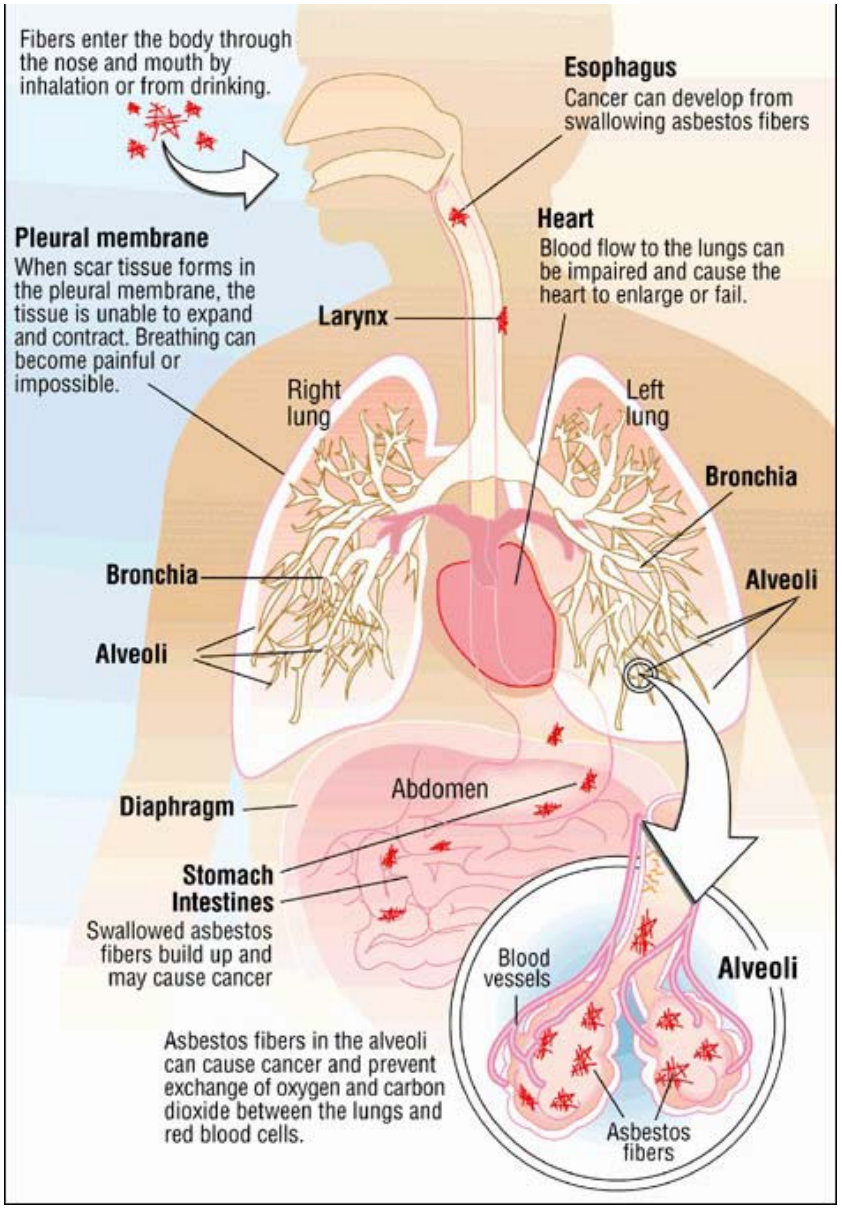
2) Chemical reactivity of surface (must account for surface components – transition metals and coatings), and release of free radicals



3) Surface area presented to target organ (dose)

4) Solubility (if it may disperse before causing a reaction)

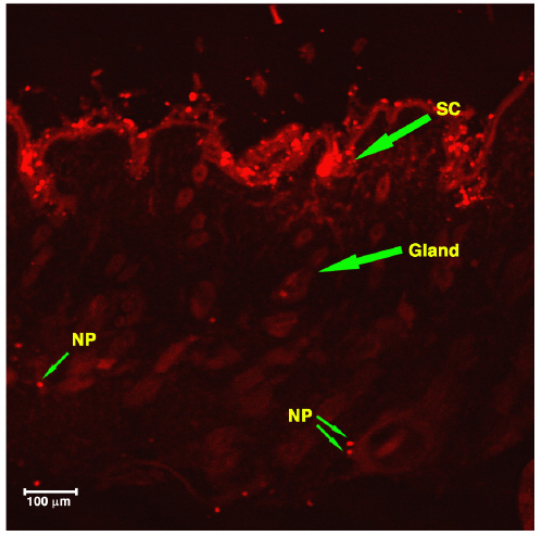
Modes of Exposure – health effects



1) Inhalation (in manufacturing and research environments)

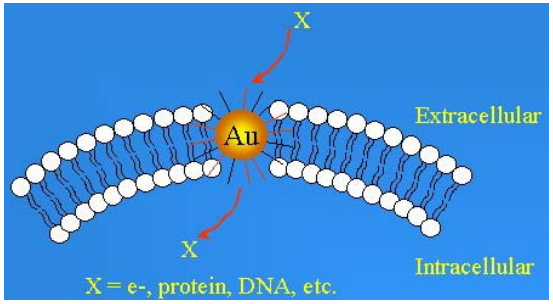
- nano-sized particles (TiO_2, Carbon black, ZnO_2, FeO)
  - high proportion deposits into deep lung
  - may go through cell membrane –
    - interfere with cell functions such as motility and ability to remove bacteria
  - Could enter nerve and translocate to brain
  - Need research on proper procedures for handling, PPE, case of accidental emissions
- tubular forms (such as carbon nanotubes)
  - May be similar to asbestos fibers – persistent ⌫ cancer causing
  - Exposure, in-vitro and in-vivo (mammalian) studies needed; and started

Modes of Exposure – health effects



2) Dermal (from cosmetics – sunscreen and make-up)

- nano-sized particles (TiO_2 , Fe_2O_3, ZnO_2)
  - – if penetrates skin – potential to generate free radicals that can damage DNA
  - – all tests performed by industries (confidential) on intact epidermis – (has FDA approval)
    - o Concerns if skin is damaged by sunburn or eczema
- future - drug delivery through skin
  - – studies in rats show ability of nano molecules to pass through skin
  - – nanoparticles have ability to enter cells, and obstruct normal cell function



3) Ingestion (remediation/waste streams ⌫ food chain)

- unknown effects – dependent on particle

Workplace sampling procedures

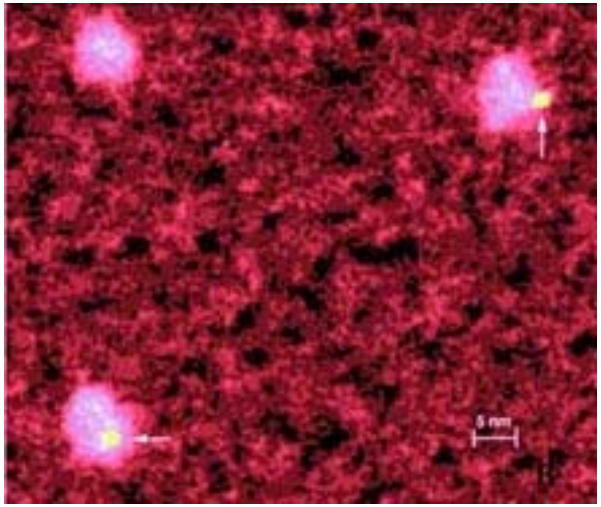
- Procedures draw upon sampling for respirable fractions
  - Condensation particle counter (CPC)
  - Scanning mobility particle sizer (SMPS)
  - Impactor (ELPI/Sioutas etc.)

Challenges

- Validity: ability to capture and retain representative sample that can subsequently be measured – is it representative of exposure conditions?
- Specificity: ability to differentiate and quantify particles of interest from the background
- Simultaneous measurements of size, surface area, shape and chemical species
- Development of a standard quality assurance scheme

Analysis methods

- Methods are dependent on knowledge of particles analyzed
  - Need for characterization of particle size, surface area, chemical reactivity, and shape
- Electron beam techniques (2-dim)
  - SEM, TEM (in vacuum), etc
- Atomic Force Microscopy (3-dim)



Challenges

- Current instruments:
  - large, expensive, non-portable, require highly trained operators – not suitable for field application; dosimeters long way into future
- Need for an international measurement standard for nanoscalar metrics – dimension, chemical composition, force and electrical quanta → need agreed exposure/emissions levels

Controls

- No **specific** regulatory controls in place (in discussion stage by regulators; ISO,CSA, ASTM, IEE, EU, OECD positioning)
- Possible specific areas for controls:
  - Workplace controls
    - Adjusting OELs for nanoparticulate forms of chemicals
    - Specific PPE, safe work practices
  - Classification, labeling measures, training
  - Control of emissions to air, water, land
  - Waste disposal restrictions
  - Marketing and use restrictions
  - UK Health and Safety Lab and US NIOSH
    - Decided that more information was needed to define properties and behaviour
    - Use precautionary steps in the meantime to reduce exposure
    - Internationally standardized tools needs to be developed to promote collaboration
    - Open communication with the public very important to keep publics trust

Controls – current status

- Newly developed NIOSH Nanotechnology and Health and Safety Research Program
  - Five year multidisciplinary study into the toxicity and health risks is currently underway
- OECD focusing on Policy and environmental standards
  - Looking at research needed to plug gaps
  - ISO TC229 focuses on Metrology, Terminology, and EHS
  - CSA/NRC leading Stds process; workshop with Feds and provinces held in April 2006
  - Federal Inter-ministerial Liaison Group in place; EC/HC biggest players
  - Alberta a big player with NINT; Quebec with NanoQuebec; Ontario and BC getting organized

Summary: Issues and concerns

Current exposure in laboratories and manufacturing processes unknown

- Toxicological studies limited, but started; lack of information on PPE and handling, but growing
- Big players implementing rigorous prevention systems
- Social and ethical issues re poor regions being left behind though with potentially great benefits

- Long-term fate of nanoparticles (nps) from products → environment unknown for many current applications
  - Limited understanding of transport of nps in air, water, and soil → effects from exposure to humans, animals, plants
  - A lot of work in progress in US, China, Japan, Scand Countries, EU; Canadian institutions getting involved

Summary: Issues and concerns

- Lack of information on safety of nps in current dermal applications; interaction with cells, heart, nervous system
- Should chemicals in nano form be treated as new chemicals as characteristics are different?
- Same exposure limits for chemicals in nano form though responses known to be different; no new proposals on table as yet
- Flammability and explosivity characteristics still to be determined

Impact of Nanotechnology on Education Systems

- Students must be aware of the science, theory, applied engineering and socio-political aspects of nanotechnology
- In labs and pilot development, one must be mindful of the EHS aspects to protect employees, public and ecosystem
- Schools must be a resource to the public to answer questions on technology, health impact and socio-ethical issues
- Track the popular literature for outcome of standardization efforts, consumer, ecosystem and health issues

NANO $ VALUE

Researchers	New Knowledge	$
Graduates	Capacity for R&D commercialization	$
Equipment designers/developers to generate/handle	New ability to analyze; miniaturize	$→ $$$
Integrators	Abling existing systems to perform better, faster, cheaper?	$→ $$
Materials	New products for integration into systems (small volume-higher value)	$→ $$$
Trade	New products, enabled products – social contribution	$→ $$
Financing	New opportunities	$→ $$
Under-developed Region	Not playing initially or ever	$→ -$
Pharma	New ways to diagnose/treat	$→ $$$$
Electronics	Smaller, faster, different	$→ $$
Agriculture	Higher performance; less needed	$→ $$
Medicine	Better,faster, diagnostics/treatment	$→ $$