Nanomaterials: friend or enemy?

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LIFE AT THE
NANO TECHNOLOGY
FACTORY

“Okav nanobe...”
Overview

• Introduction
  – Nano?
    • Definition
    • Use?

• Important Physico-chemical parameters?
  – Size
  – Dissolution
  – Shape
  – Crystal structure & more
  – Surface characteristics (Protein corona & charge)

• Conclusions
**Nanomaterial** = at least one dimension <100 nm, including biological nanomaterials, ambient ultrafine particles (UFP) and engineered nanomaterials.

**(Nanoparticle** = all dimensions <100 nm)
<table>
<thead>
<tr>
<th>Glucose</th>
<th>Protein</th>
<th>DNA</th>
<th>Virus</th>
<th>Cell</th>
<th>Diameter hair</th>
<th>Tennis Bal</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Glucose" /></td>
<td><img src="image2" alt="Protein" /></td>
<td><img src="image3" alt="DNA" /></td>
<td><img src="image4" alt="Virus" /></td>
<td><img src="image5" alt="Cell" /></td>
<td><img src="image6" alt="Diameter hair" /></td>
<td><img src="image7" alt="Tennis Bal" /></td>
</tr>
</tbody>
</table>

Nanoparticles

- Ag
- SiO$_2$

<table>
<thead>
<tr>
<th>10$^{-1}$</th>
<th>1</th>
<th>10</th>
<th>10$^2$</th>
<th>10$^3$</th>
<th>10$^4$</th>
<th>10$^5$</th>
<th>10$^6$</th>
<th>10$^7$</th>
<th>10$^8$</th>
</tr>
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<td></td>
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</table>

Nanometers

- Nanoparticles:
  - Ag: 50 nm
  - SiO$_2$: 100 nm
Applications of nanomaterials

Applications/Examples
• Sports equipment’s (bikes, rackets, …)
• Ketchup
• Food packaging, textiles
• Solar cells, batteries
• Sun creams, cosmetics
• Medicine (cancer therapy, imaging, drug delivery, …)

Effect
➢ Improved strength, durability, lightness
➢ Flow enhancing agent
➢ Antimicrobial
➢ Enhanced reactivity
➢ Anti-UV effects
## Added value of Nanomaterials?

**Effects and applications due to the reduced dimension**

<table>
<thead>
<tr>
<th>Effect</th>
<th>Examples of application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhanced reactivity</td>
<td>→ Catalysis, solar cells, batteries</td>
</tr>
<tr>
<td>Changing optical properties</td>
<td>→ Quantum dots</td>
</tr>
<tr>
<td>Higher resistivity</td>
<td>→ Electronics</td>
</tr>
<tr>
<td>Wear resistance</td>
<td>→ Hard coatings, tools</td>
</tr>
</tbody>
</table>

Nano is more than small size

### Engineered nano particles/materials

= manufactured nanomaterials that are designed to achieve particular physico-chemical properties that relate to the product application
Important physico-chemical properties

- Size & size distribution
- Agglomeration / aggregation state
- Shape
- Crystal structure
- Chemical composition – including spatially averaged (bulk) and spatially resolved heterogeneous composition
- Surface area
- Surface chemistry
- Surface charge
- Porosity

**Dissolution**

Principles for characterizing the potential human health effects from exposure to nanomaterials: elements of a screening strategy Ober dorster et al.; PFT 2005
Important physico-chemical properties

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- Surface charge
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- Dissolution
Nanoparticles have a much larger surface area than the same amount of material in bulk form.
Size & surface area
Rats

Mice

Percent Neutrophils

TiO₂ Mass

Oberdörster et al Environmental Health Perspectives, 113, 2005
Size & Systemic uptake of nanomaterials

Kreyling et al *Inhalation Toxicology*, 2009; 21(S1): 55–60
New risks/hazards?
• Probably Yes

Why?
- Different (more) toxicity
  - Surface area?
- Systemic delivery
  - Higher/different internal exposure/dose
Important physico-chemical properties

- Size & size distribution
- Agglomeration / aggregation state
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- **Dissolution**
Decreased Dissolution of ZnO by Iron Doping Yields Nanoparticles with Reduced Toxicity .... Xia et al. ACSNano 2011
Decreased Dissolution of ZnO by Iron Doping Yields Nanoparticles with Reduced Toxicity... Xie et al. ACSNano 2011
Dissolution

• Metal (-oxides) NP’s can release significant amount metal ions

→ toxicity not necessarily depending on NP but on ions
+ Dissolution can generate oxidative stress.

Remark:
- In some instances NP & ions have additional effect
- Biodistribution of ions ≠ NP’s (Trojan horse effect)
Recommended physicochemical properties to be characterized

- Size & size distribution
- Agglomeration / aggregation state
- **Shape**
- Crystal structure
- Chemical composition
- Surface area
- Surface chemistry
- Surface charge
- Porosity

- **Dissolution**
SHAPE

Nano-ZnO: One chemistry, many shapes
Courtesy of Prof. Z.L. Wang, Georgia Tech
SHAPE

Carbon nanotubes introduced into the abdominal cavity of mice show asbestos-like pathogenicity in a pilot study

CRAIG A. POLAND¹, RODGER DUFFIN¹, IAN KINLOCH², ANDREW MAYNARD³, WILLIAM A. H. WALLACE¹, ANTHONY SEATON⁴, VICKI STONE⁵, SIMON BROWN¹, WILLIAM MACNEE¹ AND KEN DONALDSON¹*

Nature Nanotechnology May 20 2008
Specific properties
Carbon nanotubes

Figure 2 The frustrated phagocytosis paradigm as it relates to long and short fibres of asbestos (left) and various forms of carbon nanotubes (right). When confronted by short asbestos fibres or tangled, compact carbon nanotube 'particles' the macrophage can enclose them and clear them. However, the macrophage cannot extend itself sufficiently to enclose long asbestos or long nanotubes, resulting in incomplete or frustrated phagocytosis, which leads to inflammation.

Donaldson et al. Particle and Fibre Toxicology 2010, 7:5
Occupational Exposure to Carbon Nanotubes and Nanofibers
SHAPE plays a role

• Delivery - bioavailability
  – Inhalation & clearance
  - Cellular uptake

• Mechanical damage
  – Needle vs spheres

• Time of exposure
  – Excretion & Biopersistent
Recommended physicochemical properties to be characterized

- Size & size distribution
- Agglomeration / aggregation state
- Shape
- **Crystal structure**
- *Chemical composition*
- Surface area
- Surface chemistry
- Surface charge
- Porosity

- **Dissolution**

Principles for characterizing the potential human health effects from exposure to nanomaterials: elements of a screening strategy Oberdorster et al.; PFT 2005
Crystal structure

- Carbon based materials (all “pure” C)
  - Existing material:
    - [Carbon Black: filling material – “toner” ink]
    - Fullerenes (filling - lubricating)
    - Carbon nano tubes (filling – electronics?)
Crystal structure

- Crystal structure (or absence) is important

- Structure defects (lattice defects)
  - Crystalline Silica (µm)
  - Carbon nanotubes

- Impurities
Recommended physicochemical properties to be characterized

- Size & size distribution
- Agglomeration / aggregation state
- Shape
- Crystal structure
- Chemical composition
- Surface area
- Surface chemistry
- Surface charge
- Porosity

- Dissolution
Biomolecular coronas provide the biological identity of nanosized materials

Marco P. Monopoli\textsuperscript{1,2}, Christoffer Åberg\textsuperscript{1}, Anna Salvati\textsuperscript{1,2} and Kenneth A. Dawson\textsuperscript{1*}
Surface Charge & Chemistry

Conclusions

• Biodistribution/health effects depends (partly) on surface and **corona** formation

Corona

• Dependent on characteristics of NP & milieu (tissue…)
• Dynamic system
• Use to deliver compounds
• Use to suspend NP
  – Pulmonary surfactant, serum proteins…
• Changes characteristics of NP
  – Size, surface charge, …
• Corona can be used to identify the potential toxicity?
Recommended physicochemical properties to be characterized

- Size & size distribution
- Agglomeration / aggregation state
- Shape
- Crystal structure
- Chemical composition
- Surface area
- Surface chemistry
- Surface charge
- Porosity
- Dissolution

All affect biological effects

But not in all circumstances in the same extend

Interrelated effects
Part 2: Risk assessment
Risk Characterisation/Assessment

Characteristics of nanomaterial

Hazard assessment
- Hazard identification
- Dose response assessment

Exposure assessment
- External dose
- Internal dose

Risk characterisation
Is Hazard sufficiently assessed?
Control Banding respecting precautionary principle

Generic risk evaluation technique & control of those risks

<table>
<thead>
<tr>
<th>Exposure/Hazard</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
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<tr>
<td>High</td>
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Consists of:
- grouping the health hazards=toxicity (risk bands),
- exposure potential (exposure bands)
  ➔ combining these elements to generate a set of controls (control bands)
Typical Control Bands Approach (as defined for chemicals)

<table>
<thead>
<tr>
<th>1-General Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A good standard of general ventilation and good work practices.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2-Engineering Control</th>
</tr>
</thead>
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<td>Typically local exhaust ventilation, but also includes other types of engineering controls, but not containment.</td>
</tr>
</tbody>
</table>

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<tr>
<th>3-Containment</th>
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<tr>
<td>Completely contain or enclose the hazard, such as inside a glovebox.</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>4-Special</th>
</tr>
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<tbody>
<tr>
<td>Expert advice is needed in selecting appropriate control measures.</td>
</tr>
</tbody>
</table>
ASSESS HAZARDS for NanoMaterials
Possible hazard criteria

**HIGH Hazard**

**solubility and dispersion capacity**
- Water insoluble material
- Biopersistant material
- Material with high dispersion capacity size and shape.
- Powders with diameter < 10 nm
- High aspect ratio material
- Fibre/needle shaped material

**toxicity of the (parent) material used?**
- toxic parent material (carcinogenic, mutagenic, repro-toxic)
- contains transition metals (parent or surface treatment, catalyst)
- is functionalized with toxic, mutagenic, repro-toxic ...
- tends to have highly reactive surface
ASSESS EXPOSURE for NanoMaterials
Nature of the work?

HIGH exposure potential:

Proximity & duration of manipulation.
- Manipulations within breathing zone < 0.5 m
- Duration manipulations = every day / whole day

Nature of the activity.
- Manipulations can disrupt the material (scraping, cutting, slicing, polishing, ...)
- Spraying of aerosols containing NM
- Mechanical cleaning (scraping, blasting, vacuum cleaning)
- Cleaning of dust collection systems to capture NM
Conclusions

• Exposure ~ natural (environmental NPs) but specific exposure at work & in consumer products

• Nanotechnology = use nano-specific features → specific physico-chemical characteristics

• Risk not well enough know
  → Careful handling / avoid exposure

• Risk banding can be used including the necessary caution
Thank You For Your Attention