Occupational Exposure Assessment for Engineered Nanomaterials

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Overview

- Exposure Scenarios
- Specific challenges for exposure assessment for nanomaterials
- Tiered exposure assessment approach
- Conclusions
Exposure to nanomaterials – can it happen?

- Pristine NP
- Incorporated into a formulation
- Mixed with waste products
- Interacting with biological molecules
- Interacting with environmental molecules
Scenarios of NP production and use

time
Exposure scenarios for carbon nanotubes, fibres used in composite materials

ES1 Laboratory scale
ES2 Manufacture using CVD
ES3 Manufacture using AVD
ES4 Intermediate products
ES5 Manufacture of solid products
ES6 Professional use of solid products
ES7 Consumer use of solid products
ES8 Manufacture of textiles containing CNTs
ES9 Manufacture of textile products containing CNTs
ES10 Manufacture of textile products coated with CNTs
ES11 Professional use of textile products containing CNTs
ES12 Consumer use of textile products containing CNTs
ES13 Professional use of textiles coated with CNTs
ES14 Consumer use of textiles coated with CNTs
ES15 Manufacture of concrete masterbatch containing CNTs
ES16 Manufacture of concrete products containing CNTs
ES17 Professional use of concrete masterbatch containing CNT
ES18 Professional use of concrete products containing CNT
ES19 Consumer use of concrete masterbatch containing CNT
ES20 Consumer use of concrete products containing CNT
ES21 Manufacturing of liquid products containing CNT (e.g. paint)
ES22 Professional use of liquid products containing CNT
ES23 Consumer use of liquid products containing CNT
ES24 Recycling and disposal of products containing CNT
## Publications on HARNs exposure

<table>
<thead>
<tr>
<th>Lead Author</th>
<th>Pub date</th>
<th>nanomaterial</th>
<th>tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maynard</td>
<td>2004</td>
<td>SWCNT</td>
<td>Production and handling</td>
</tr>
<tr>
<td>Methner</td>
<td>2006, 2007</td>
<td>Carbon nanofibres</td>
<td>Handling of CNF and processing (sawing) of composites</td>
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<td>Han</td>
<td>2008</td>
<td>MWCNT</td>
<td>CNT manufacture and processing (research)</td>
</tr>
<tr>
<td>Bello</td>
<td>2008</td>
<td>MWCNT</td>
<td>Recovery and handling of CNT</td>
</tr>
<tr>
<td>Bello</td>
<td>2009</td>
<td>MWCNT</td>
<td>Dry and wet machining of composites</td>
</tr>
</tbody>
</table>
Sustainable development for nanotechnology

- ENMs
- Exposure Scenarios
  - Improved RMMs
  - Exposure Assessment
  - Human Toxicology
  - Human Risk Assessment
    - Risk acceptable
    - Compliance, Health surveillance, Epidemiology
  - Unacceptable risk
  - Improved RMMs
    - Modification of ENM
Changes are difficult to make

- Approximate ratio of publications on Synthesis & Applications : Toxicity: Exposures

>1000 : 10-100: 1

*With permission from Dhimiter Bello*
Why measure?

- Identify and characterise sources of nanoparticle emissions
- Assess effectiveness of control measures
- Ensure compliance with OEL or in-house exposure standard
- Regulatory risk assessment, eg for REACH
- Investigation of determinants of exposure, eg to support exposure modelling
- Provide exposure estimates for human health studies (epidemiology, health impact assessment)

Different approaches are required for different situations
Exposure assessment data

- Exposure assessment is not just concentration measurement.
- Information is required on ...
  - Route of exposure
  - Intensity, Frequency and Duration
  - Physico-chemical characterisation
  - Variability (temporal and spatial)
  - Risk Management Measures
    - Ventilation
    - PPE
  - Operational Conditions
    - Process conditions
    - Time activity patterns of workers
Exposure Scenarios - REACH

• Description of conditions suitable to ensure control of risks related to the uses of a substance during its entire life cycle.
  • Operational conditions determining the exposure (e.g. duration of task)
  • Practical risk management measures (RMM) suitable/needed to prevent, reduce or limit risks (e.g. exhaust ventilation)

• Explanation how the exposure estimates related to these conditions and RMM have been derived.

• Title of exposure scenario indicting for which uses it can be applied

• Boundaries within which the exposure scenario is applicable
Specific challenges for exposure assessment for nanomaterials

- What metric should be used for measuring nanoparticle exposure?
- Can we discriminate nanoparticles and other nano-objects from background aerosol?
- How can we use size information and what is the maximum size we should measure?
- Can HARN such as CNT or nanowires be measured using methods for, or derived from, or analogous to current methods for fibres?
- What measurement methods and models are available?

E.g. Maynard and Aitken 2007
Specific challenges with nano

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Exposure metrics

**ENM properties**
- Mass
- Number
- Surface area
- Chemistry/impurities
- Solubility
- Morphology
- Surface charge
- Etc.

- No universal exposure metric for all ENMs based on physico-chemical characteristics
- Exposure characterisation and quantification
- Need for closer collaboration between toxicologists and exposure assessment scientist to determine biological relevant metrics
- Exposure variability (temporal and spatial)
# Divers nanoparticles

## Classifying diverse nanoparticles

<table>
<thead>
<tr>
<th>Compact/Sphere</th>
<th>Heterogeneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogeneous</td>
<td>Core-surface</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>High aspect ratio</th>
<th>Heterogeneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogeneous</td>
<td>Distributed</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Complex non-spherical</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogeneous</td>
<td>External stimuli</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Homogeneous agglomerates</th>
<th>Multifunctional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single particle class</td>
<td>Complex responses</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heterogeneous aggregates</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Many particle classes</td>
<td></td>
</tr>
</tbody>
</table>

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Specific challenges with nano

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E.g. Maynard and Aitken 2007
Background discrimination


Fig. 3. Average number and mass variation of all measurement days and positions. The production phases are (i) background phase (0–125 min), (ii) reactor system cleaning phase (125–174 min), (iii) starting phase (174–234 min), (iv) steady-state phase (234–381 min) and (v) decline phase (381–441 min). The box plots indicate the median and 25th and 75th percentile. The whiskers indicate the minimum and maximum levels after the outliers, values >1.5 times the inter-quartile range, have been excluded. The open circles represent outliers.
Specific challenges with nano

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E.g. Maynard and Aitken 2007
Pilot plant CNT production Average Particle Size Distributions

![Graph showing particle size distributions and concentration](image-url)
Use of size information

Fig. 2 – FMPS particle size distribution during listed process stages.

Bello et al. (2008)
Size cut-off for nanoparticles (100nm)?

- What is the likely difference in risk between particles of 102 and 99 nm?
- Single NPs rarely present in the workplace due to presence of aggregates and coagulation and scavenging of free single NPs after release
- However, all particle in the respirable size range can enter and deposit in the deep lung including aggregates and agglomerates
- Subsequent behaviour of these particles in biological fluids is unclear
Specific challenges with nano

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- What measurement methods and models are available?  
  E.g. Maynard and Aitken 2007
Measurement of HARN

- Standard approach for counting fibres (WHO 1997) using phase contrast optical microscopy
- Length > 5 µm (5000 nm) a width < 3 µm (3000 nm), and a length to width ratio (aspect ratio) greater than 3:1
- However:
  - Limited visibility of HARN for optical analysis;
  - higher magnifications necessary to detect HARN means that the field of view (fov) will be much smaller, decreasing the likelihood of finding countable fibres (i.e. with both ends in the counting field), and increasing the number of fields to be counted
  - The highly agglomerated nature of some types of HARN (typically single walled carbon nanotubes) is likely to make additional identification of single fibres problematic.
SEM analyses pilot plant CNT production

(X 1500)  

(X 5000)  

(X 8000)
Specific challenges with nano

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E.g. Maynard and Aitken 2007
<table>
<thead>
<tr>
<th>Instrument</th>
<th>Number</th>
<th>Mass</th>
<th>Surface area</th>
<th>PSD</th>
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<tbody>
<tr>
<td>condensation particle counter</td>
<td>CPC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>optical particle counter</td>
<td>OPC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>size selective personal sampler</td>
<td>SSPS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>size selective static sampler</td>
<td>SSSS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tapered element oscillation microbalance</td>
<td>TEOM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>diffusion charger - NSAM</td>
<td>DC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scanning\fast mobility particle sizer</td>
<td>SMPS</td>
<td>FMPS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>electrical low pressure impactor</td>
<td>ELPI</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>electron microscopy</td>
<td>EM</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conceptual model for nano exposure

(Schneider et al, submitted)
Exposure Assessment for Nano

- Most equipment for measurement NP still “research” equipment
- FP7 NANODEVICE aimed at developing easy to use personal samplers for NPs. However, unlikely to solve all challenges
- Exposure assessment generally challenging and expensive, for NPs even more so
- Therefore, a tiered approach for exposure assessment is recommended
Tiered Exposure Assessment

- **Tier 1: Identify and characterise the source of emissions**
  - Gain an understanding of where particles may be emitted for the process CPC/OPC
  - Critical to consider ambient or background particle counts
  - Results from simulation experiments
  - Physico-chemical characterisation
  - Collection of particles onto a filter followed by inspection by optical microscope of by SEM/TEM if available and or chemical analysis

- If evidence for emissions of NPs (whether or not as part of other aerosols) then go to Tier 2 or improve control
Tiered Exposure Assessment

- **Tier 2**: Use of exposure/control banding models
  - Current in development
  - Eg Stoffenmanager-NANO
  - If exposure/risk cannot be excluded than go to Tier 3 or improve controls
Tiered exposure assessment

- **Tier 3: Concentration measurement**
  - Using stationary instruments
  - Particle number, size, surface area
  - TEM analyses
  - Compare with background levels
  - Determine the likelihood of exposure (Brouwer et al 2009)
  - If exposure is likely go to Tier 4 or improve control
## Assessment of likelihood of exposure

**Nano dataset – lay-out**

Likelihood, (preliminary) Decision log criteria NANOSH

<table>
<thead>
<tr>
<th>Δ concentration</th>
<th>On-line device</th>
<th>Electron Microscopy</th>
<th>Observations</th>
<th>Overall</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>P-value</td>
<td>ratio</td>
<td>likelihood</td>
<td>TEM</td>
</tr>
<tr>
<td>≥ 0.05</td>
<td>≤ 0.5</td>
<td>&gt; 1</td>
<td>-</td>
<td>Large particles / agglomerates</td>
</tr>
<tr>
<td>&lt; 0.05</td>
<td>&gt; 0.5</td>
<td>&gt; 1- &lt; 1.05</td>
<td>±</td>
<td>Agglomerates + particles</td>
</tr>
<tr>
<td>&lt; 0.05</td>
<td>≥ 1.05</td>
<td>+</td>
<td>Particles + small agglomerates</td>
<td>yes</td>
</tr>
</tbody>
</table>

(Brouwer et al 2009)
Tiered exposure assessment

- Survey aimed at assessing personal exposure
  - Personal exposure measurements using filters or grids suitable for SEM/TEM or chemical analyses
  - Biological samples (exhaled breath)
- If exposure is likely to be high then improve controls
Conclusions

• Still relatively few exposure studies published (more emerging)
• Limited range of materials and tasks. Scenarios have addressed synthesis, handling and use
• Most studies have found some evidence of exposure, often to much larger agglomerates
• Challenges for measurements are unlikely to be resolved in near future
• Need for harmonisation of exposure surveys and data collection/storage
• Need for development of tiered exposure and risk assessment approaches, including the development of validated exposure models