Value-chain case-studies with high quality conceptual information for model testing

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OUTLINE

- Current challenges in nano risk governance
- Models and tools for risk assessment
  - CaLIBRAte models and tools
  - Input parameters required
- Performance testing
  - Identification of data sources
  - Evaluation of data availability to cover requirements by the different models
  - Inventory of case studies
  - Evaluation of data quality
- Example of a case study
  - Measured vs. modeled exposures
- Conclusions and research needs
Fast moving market of nanomaterials

Risk assessment approach is inadequate for enabling safe use of NM. Lacking robust sources of quantitative data

So far, the existing nano-specific control banding tools and quantitative models were not thoroughly tested, calibrated and validated!

Next generation (system-of-systems) risk governance portal for assessment and management of human and environmental risks of NM

- Design safer nano-enabled products
- Facilitate decision-making on risk uncertainties
- Support compliance with regulatory frameworks
- Provide homogenous rules for safe management of NMs

See poster number A91810KJ!!
### SELECTION OF MODELS AND TOOLS FOR RISK ASSESSMENT

<table>
<thead>
<tr>
<th>No.</th>
<th>Model name</th>
<th>Application area</th>
<th>Owner</th>
<th>Model type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ANSES tool</td>
<td>Work</td>
<td>ANSES</td>
<td>CB</td>
</tr>
<tr>
<td>2</td>
<td>ISO TS 12901 CB tool</td>
<td>Work</td>
<td>ISO</td>
<td>CB</td>
</tr>
<tr>
<td>3</td>
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<td>Work</td>
<td>LLNL (USA)</td>
<td>CB</td>
</tr>
<tr>
<td>4</td>
<td>StM Nano</td>
<td>Work</td>
<td>Cosanta (NL)</td>
<td>CB / RM</td>
</tr>
<tr>
<td>5</td>
<td>NanoSafer CB</td>
<td>Work</td>
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</tr>
<tr>
<td>6</td>
<td>ConsExpo Nano</td>
<td>Cons</td>
<td>RIVM</td>
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</tr>
<tr>
<td>7</td>
<td>BAUA SprayExpo</td>
<td>Work</td>
<td>BaUA (DE)</td>
<td>QEA</td>
</tr>
<tr>
<td>8</td>
<td>RiskofDerm</td>
<td>Work</td>
<td>TNO</td>
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<td>9</td>
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<td>IOM</td>
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</tr>
<tr>
<td>10</td>
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<td>Env/Cons/Work</td>
<td>FOPH (CH)</td>
<td>Risk Cat</td>
</tr>
<tr>
<td>11</td>
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<td>Env/Cons/Work</td>
<td>EMPA/TNO</td>
<td>Risk Benefit</td>
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<td>12</td>
<td>SUNDS</td>
<td>Env/Cons/Work</td>
<td>UNIVE / GD</td>
<td>RA / RM</td>
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<tr>
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<td>GuideNano</td>
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</tr>
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<td>14</td>
<td>nano-QSAR</td>
<td>Human/Env.</td>
<td>Tomas Puzyn</td>
<td>QHA</td>
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<tr>
<td>15</td>
<td>SimpleBox4Nano</td>
<td>Env</td>
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<td>16</td>
<td>Mendnano</td>
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</tr>
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<td>NanoDuFlow</td>
<td>Env</td>
<td>WA (NL)</td>
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</tr>
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**Abbreviations:**

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**Tier 0:** Risk categorization (qualitative)

**Tier 1:** Control-banding (qualitative or semi-quantitative)

**Tier 2:** Basic predictive control banding / risk assessment (one or two box models)

**Tier 3:** Quantitative risk assessment
REQUIRED INPUT PARAMETERS
HRA tools and models

1. **Material/particle properties (200):** morphology/shape, average size, density, dustiness,…

2. **Environment/room properties (59):** room geometry, emission controls, ventilation rate,…

3. **Process properties (240):** Descriptors for emissions/concentrations (e.g. task duration and frequency, emission rate,…).

4. **Limit values/Toxicity (84):** Descriptors for the material hazardousness/toxicity (e.g. proposed OELs, DNEL, shape, and solubility).

5. **Other parameters (143):** All the variables that were not classified under the other groups. Examples of such variables include variables required for linking to other (sub)models, some natural constants, and variables for operating the numerical solvers of the models.
PERFORMANCE TESTING
Modelings vs. Measurements

Model INPUT
Real Data

Model OUTPUT
Predicted Data

Tested by comparing the modelling results with the observations (real data)

REQUIREMENT
High quality measurement data with comprehensive contextual information

- Exposure databases (NECID, GUIDEnano library)
- Data generated in EU Projects
- Literature

**Dustiness library**
- Continuous Drop & Rotating Drum
- Dustiness index
- Dustiness kinetics

**PROC-USE**
- Release data library
  - Spray
  - Mechanical wear
  - Mechanical reduction
  - Leaching

**ECEL**
- Emission control efficiency library
  - Engineered control equipment

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1 PROC-USE: Process and Product Use; Data based on Mackevicka and Hansen (2016) and Koivisto et al. (2017)
2 ECEL: Emission Control Efficiency Library for nanomaterials (Fransman et al. 2008)
EVALUATION OF DATA AVAILABILITY

Exposure databases

- **GUIDEnano library and NECID** cover most of the parameters dealing with occupational exposure requested by the HRA models.

- **Release/emission rates and OEL** are not included.

- **Some datasets are available**

- **Other databases have been identified to cover single parameters (release/emission rates, dustiness).**

<table>
<thead>
<tr>
<th>Category</th>
<th>Human exposure: occupational and consumer exposure parameter</th>
<th>NECID</th>
<th>MARINA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test substance</td>
<td>Physical/chemical characteristics (see Annex 3)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Type of product (~100% nano or intermediate/mixed product; incl. weight fraction of nano in product)</td>
<td>✔</td>
<td>✗</td>
</tr>
<tr>
<td></td>
<td>Physisorption of nanomaterial/product (liquid, powder, solid matrix)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>In case of powders: dustiness category (e.g. very high, high, medium, low)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>Exposure for powders</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td></td>
<td>Occupational exposure limits (also respirable dust)</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td></td>
<td>In case of liquid: viscosity (e.g. low, medium, high)</td>
<td>✔</td>
<td>✗</td>
</tr>
<tr>
<td></td>
<td>Product category and preferable product type</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Test subject</td>
<td>Exposed body area (cm²)</td>
<td>✗</td>
<td>✗</td>
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<tr>
<td></td>
<td>Measurement location (brushing zone, source, distance from source/person)</td>
<td>✔</td>
<td>✔</td>
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<tr>
<td></td>
<td>Amount of nanomaterial/nanoparticle used</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>Route of exposure</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>Location (inside/outside and size of room in m²)</td>
<td>✔</td>
<td>✔</td>
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<tr>
<td>Activity/Process/Methods</td>
<td>Description of exposure scenario (type, room dimensions, ventilation rate)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>Activity/application method (spraying, brushing, pouring, etc.) or description of use product (amount of product used)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>Release/emission rate (mass/time)</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td></td>
<td>Activity handling; energy factor</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>Frequency, duration of exposure and exposure pattern</td>
<td>✔</td>
<td>✔</td>
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<tr>
<td></td>
<td>Cleaning and maintenance of the room</td>
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<td>✔</td>
</tr>
<tr>
<td></td>
<td>Used exposure controls (Local &amp; General Exhaust Ventilation Monitoring; LERCGEV, personal protection equipment; PPEs, etc.) and preferably type of LERCGEV, PPE used and efficiency (air changes per hour)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>Background concentration</td>
<td>✔</td>
<td>✔</td>
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<tr>
<td></td>
<td>Activity level in room (Describes the environment in which the activity, exposure or release of nanoparticles occur, e.g. distance from the source)</td>
<td>✔</td>
<td>✔</td>
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<tr>
<td></td>
<td>Detailed description of experimental measurements and procedures</td>
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<td>✔</td>
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<tr>
<td></td>
<td>Climate conditions (temperature and relative humidity)</td>
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<td>✔</td>
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<tr>
<td></td>
<td>Description of secondary sources (diesel engines, cigarette smoke, welding, busy road, etc.)</td>
<td>✔</td>
<td>✔</td>
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## COLLECTION OF HUMAN EXPOSURE SCENARIOS

### Examples for TiO$_2$

<table>
<thead>
<tr>
<th>Phase</th>
<th>Source domain</th>
<th>Specific activity</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthesis (1)</td>
<td>Handling and transfer of bulk manufactured NM powders</td>
<td>TiO$_2$ particle collection during flame spray synthesis</td>
<td>(Koivisto et al., 2012) (NANOHEALTH)</td>
</tr>
<tr>
<td>Synthesis (2)</td>
<td>Handling and transfer of bulk manufactured NM powders</td>
<td>Jet -milling and packing processes of pigment and nano-TiO$_2$</td>
<td>(Koivisto et al., 2012) (TEKES and FinNano Program)</td>
</tr>
<tr>
<td>Synthesis (3)</td>
<td>Handling and transfer of bulk manufactured NM powders</td>
<td>Recovery and handling of TiO$_2$ NFs during product finalization</td>
<td>(Bressot et al., 2018) SANOWORK</td>
</tr>
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<td>Synthesis (4)</td>
<td>Synthesis and Handling and transfer of bulk manufactured NM powders</td>
<td>Sol-gel synthesis and handling of nano-TiO$_2$ in an industrial research laboratory (in a fume hood)</td>
<td>(Fonseca et al., 2018) SUN and HINAMOX</td>
</tr>
<tr>
<td>Synthesis (5)</td>
<td>Synthesis</td>
<td>Manufacture of TiO$_2$ Nanoparticles. Synthesis by flame pyrolysis</td>
<td>GUIDEnano library (ES377)</td>
</tr>
<tr>
<td>Synthesis (6)</td>
<td>Handling and transfer of bulk manufactured NM powders</td>
<td>Packing of TiO$_2$</td>
<td>GUIDEnano library (ES352)</td>
</tr>
</tbody>
</table>
COLLECTION OF HUMAN EXPOSURE SCENARIOS

Life cycle chain of TiO₂ and SiO₂

- Surface and spraying applications of liquids (X5)
- Deposition/thermal treatments (x2)
- Cleaning and maintenance (x2)
- Activities with relatively undisturbed surfaces (no aerosol, x2)
- Fracturing and abrasion of solid objects (x2)

- Flame pyrolysis
- Application of liquids in high speed processes
- Wet chemistry
- Laser ablation
- Movement and agitation of powders or granules (X8)
- Handling and transfer of powders (X14)

- Hot processes (X2)
- Compressing of powders or granules (x1)
- Fracturing and abrasion of solid objects (x6)

- Incineration (X2)
- Other

- Use of articles with low release (outdoor) (X8)
- Use of paints (outdoor) (X5)
- Use of textiles (washing + wearing) (X3)

- Use of photocat. coating on road (outdoor) (X2)

- Handling and transfer of NM powder (X14)
- Dispersion of intermediates/application of ready-to-use products (liq. and pow.) (X4)

- Fracturing and abrasion of solid objects (X11)

- Use of polymeric nanocomposites (outdoors) (X15)
- Use of paints (outdoor walls) (X6)

- Handling and transfer of NM powder (X1)
- Dispersion of intermediates/application of ready-to-use products (liq.) (x1)
- Hot processes (X2)
- Fracturing of solid objects (x6)

- Spraying/Rolling activities (x10)

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- Hot processes (X2)
- Compressing of powders or granules (x1)
- Fracturing and abrasion of solid objects (x6)

- Fracturing and abrasion of solid objects (x4)
- Spraying / Rolling activities (x10)

- Incineration (X2)
- Other

- Incineration (X2)
- Use of polymeric nanocomposites (outdoors) (X15)
- Use of paints (outdoor walls) (X6)

- Handling and transfer of NM powder (X1)
- Dispersion of intermediates/application of ready-to-use products (liq.) (x1)
- Surface and spraying applications of liquids (X5)
- Deposition / thermal treatments (x2)
- Cleaning and maintenance (x2)
- Activities with relatively undisturbed surfaces (no aerosol, x2)
- Fracturing and abrasion of solid objects (x2)

- Fracturing and abrasion of solid objects (x4)
- Use of paints

- Handling and transfer of NM powder (X14)
- Dispersion of intermediates/application of ready-to-use products (liq. and pow.) (X4)
- Surface and spraying applications of liquids (X5)
- Deposition / thermal treatments (x2)
- Cleaning and maintenance (x2)
- Activities with relatively undisturbed surfaces (no aerosol, x2)
- Fracturing and abrasion of solid objects (x6)

- Flame pyrolysis
- Application of liquids in high speed processes
- Wet chemistry
- Laser ablation
- Movement and agitation of powders or granules (X8)
- Handling and transfer of powders

- Handling and transfer of NM powder (X1)
- Dispersion of intermediates/application of ready-to-use products (liq.) (x1)
- Hot processes (X2)
- Compressing of powders or granules (x1)
- Fracturing and abrasion of solid objects (x6)

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- Fracturing and abrasion of solid objects (x2)

- Fracturing and abrasion of solid objects (x4)
- Use of paints

Largest number of exposure studies available: SiO$_2$ > TiO$_2$ > Ag > Cu-based
Some clear general gaps: end-of-life stages
Typical missing parameters in exposure scenarios: emission rates, dustiness, ventilation, physico-chemical properties etc. Therefore should be taken from other sources or recalculated
### DATA INVENTORY FOR PERFORMANCE TESTING

- Data quality evaluated for 67 occupational exposure scenarios

<table>
<thead>
<tr>
<th>Overall quality</th>
<th>Weighing factor</th>
<th>Total</th>
<th>Study design</th>
<th>Reliability (=Quality) parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevance parameters</td>
<td></td>
<td>1</td>
<td>0.90</td>
<td>Present in the study? (yes=1 no=0)</td>
</tr>
<tr>
<td>Is any of the NMs (TiO2, SiO2, Ag, CuO, MWCNT) investigated in the study?</td>
<td></td>
<td>0</td>
<td>Present in the study? (yes=1 no=0)</td>
<td></td>
</tr>
<tr>
<td>Is the activity belonging to any of these source domains (Release of primary particles during actual synthesis; Handling of bulk aggregated/agglomerated nanopowders; Spraying or dispersion of ready-to-use nanoproduct)?</td>
<td></td>
<td>0</td>
<td>Present in the study? (yes=1 no=0)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Study design</th>
<th>Present in the study? (yes=1 no=0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background measurements (mass preferably; If mass concentrations are not available a factor of 0.5 should be used)</td>
<td>4</td>
</tr>
<tr>
<td>Offline measurements</td>
<td>1</td>
</tr>
<tr>
<td>Personal sampling (mass preferably; If mass concentrations are not available a factor of 0.5 should be used)</td>
<td>0,5</td>
</tr>
<tr>
<td>NF and FF measurements in study? (mass preferably; If mass concentrations are not available a factor of 0.5 should be used)</td>
<td>0,5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Substance information</th>
<th>Present in the study? (yes=1 no=0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NM identity (SDS of the specific material available)</td>
<td>5</td>
</tr>
<tr>
<td>Primary particle size/particle size distribution</td>
<td>3</td>
</tr>
<tr>
<td>Weight fraction (of NM in the product)</td>
<td>3</td>
</tr>
<tr>
<td>Morphology/Shape of the NM</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activity information</th>
<th>Present in the study? (yes=1 no=0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description of the activity</td>
<td>5</td>
</tr>
<tr>
<td>Indoor/outdoor</td>
<td>3</td>
</tr>
<tr>
<td>Production volume / use rate</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indoor/outdoor information</th>
<th>Present in the study? (yes=1 no=0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of the activity (h)</td>
<td>3</td>
</tr>
<tr>
<td>Used RMM/ local controls</td>
<td>5</td>
</tr>
<tr>
<td>Used PPEs - Note that for model testing WP6 will consider that no PPEs have been used</td>
<td>not considered in the formula</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Completeness parameters</th>
<th>Present in the study? (yes=1 no=0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dustiness of NM</td>
<td>5</td>
</tr>
<tr>
<td>Emission rate</td>
<td>3</td>
</tr>
<tr>
<td>Daily cleaning and monthly inspection</td>
<td>3</td>
</tr>
<tr>
<td>Room Size (m³)</td>
<td>3</td>
</tr>
<tr>
<td>Ventilation system (natural, mechanical, …)</td>
<td>3</td>
</tr>
<tr>
<td>Air exchange per hour (#/h)</td>
<td>3</td>
</tr>
</tbody>
</table>

47 studies were classified with rank > 0.7 [0 to 1]
EXAMPLE OF A CASE STUDY
Measured vs. modeled exposures

Pouring 700 g of CuO in a laboratory fume hood

MEASURED EXPOSURES
Pouring 700g CuO under a fume hood

- CuO (CAS No.1317-38-0)
- Primary size 40±10 nm

Material and safety data entered

Manufacturer: PlasmaChem GmbH
CAS: 1317-38-0
Relevance: Yes
Coated: No
Known shape: Yes
Morphology: Spherical / Isometric
Shortest dimension: 40 nm
Size is known: No
Average size: No
Size range known: No
Surface area: 15 m²/g
Relative density: 6.5 g/cm³
Solubility: Insoluble (< 1 g/L)
Respirable dustiness: 1.04 mg/kg

Exposure situation data entered

Process type: Powder handling
Energy level: H2 (0.25): Low energy - (e.g. < 5 cm drop height; handling of contaminated or leaking bags)
Amount used in cycle: 0.7 kg
Cyclus duration: 1 min
Number of cycles per day: 1 times
Pause between cycles: 0 min
Mass handled per task in cycle: 0.7 kg
Time required per task in cycle: 1 min
Length room: 7.25 meters
Width room: 5.24 meters
Height room: 3.52 meters
Room air exchange: n/hour times per hour
Activity level room: Moderate

Local control (fume hood) factor = 0.01

Sampling locations:
- NF (in the fume-hood)
- FF (4 m away from fume-hood)
MEASURED EXPOSURES
Pouring 700g CuO under a fume hood

- NF (in the fume-hood)
- FF (4 m away from fume-hood)

CuO average exposure level = 9.2 μg m⁻³

Ratio NF/FF = 2.8

NP exposure may occur if the fume-hood is not working properly!
CuO average exposure level = 9.2 μg m\(^{-3}\)

An appropriate fume hood with an adequate sash height of 0.3–0.5 m and face velocities ranging from 0.1 to 0.4 m s\(^{-1}\) is sufficient exposure control.

Ratio NF/FF = 2.8

NP exposure may occur if the fume-hood is not working properly!
**ASSESSMENT BY TIER 2**

NanoSafer v 1.1

---

**MODELED EXPOSURES**

*Pouring 700g CuO under a fume hood*

<table>
<thead>
<tr>
<th>Toxicity Exposure</th>
<th>0.76-1.00</th>
<th>0.51-0.75</th>
<th>0.25-0.50</th>
<th>0.00-0.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;1.00</td>
<td>RL5</td>
<td>RL5</td>
<td>RL5</td>
<td>RL5</td>
</tr>
<tr>
<td>0.51-1.00</td>
<td>RL5</td>
<td>RL5</td>
<td>RL4</td>
<td>RL4</td>
</tr>
<tr>
<td>0.26-0.50</td>
<td>RL5</td>
<td>RL4</td>
<td>RL4</td>
<td>RL3</td>
</tr>
<tr>
<td>0.11-0.25</td>
<td>RL4</td>
<td>RL4</td>
<td>RL3</td>
<td>RL2</td>
</tr>
<tr>
<td>&lt; 0.11</td>
<td>RL4</td>
<td>RL3</td>
<td>RL2</td>
<td><strong>RL1</strong></td>
</tr>
</tbody>
</table>

**RL1: Very low toxicity and low exposure potential**

---

**Result of assessment**

- Estimated hazard level: 0.2
- The hazard level is estimated based on:
  - High aspect ratio material: No
  - A high volume specific surface area of 97.50 m²/cm³
  - OEL of analogue bulk material: 1 mg/m³
  - Solubility: Insoluble (< 1 g/L)
  - Presence of surface coating: No
  - Known hazards of analogue bulk material

---

**NF=1.5 μg m⁻³ < M_{NF real work environment} (9.2 μg m⁻³)**

---

**OEL_{nano} = OEL \cdot \frac{30.1}{SSA_{nano}}**

**EXP_{acute} = \frac{C_{acute}}{2 \cdot OEL_{nano}}**

**EXP_{8-hour} = \frac{C_{8-hour}}{OEL_{nano}}**

---

**Specific density of the nanomaterial (g/cm³)**

**Specific surface area of the nanomaterial [SSA]; m²/g**
ASSESSMENT BY TIER 2
Mass-balance 2-box model (NF/FF)

Modelling parameters:
- \( Q_{TOT} \): 1200 m\(^3\) h\(^{-1}\) Known
- \( Q_{LEV} \): 300 m\(^3\) h\(^{-1}\) Known
- \( Q_{FF} \): 900 m\(^3\) h\(^{-1}\) Known
- \( \lambda \): 9 h\(^{-1}\) Known (\( Q_{TOT} \)/\( V_{FF} \))
- \( V_{FF} \): 133.6 m\(^3\) Known
- \( dM/dt \): 700 g min\(^{-1}\) Known
- \( V_{NF} \): 8 m\(^3\) Assumed, same as Cherrie (1999)
- \( \beta \): 10 m\(^3\) min\(^{-1}\) Assumed

\[ V_{FF}, C_{FF} \]
\[ Q_{TOT} \]
\[ Q_{LEV} \]
\[ Q_{FF} \]
\[ V_{NF}, C_{NF} \]
\[ dM/dt \]
\[ V_{NF} \]
\[ \beta \]

**Particle removal by ventilation**

**Emission source strength**

**Compartment concentration**

**Pouring process under fume hood**

\[ DI_m \pm \sigma \]

\[ S_c \]

\[ M_{NF} \]

\[ M_{NF} \text{ modeled} \]

\[ M_{FF} \text{ modeled} \]

- **WELL PREDICTED!!**

**Pouring 700g CuO under a fume hood**

- **By continuous drop dustiness test (mg s\(^{-1}\))**

- **Fume cupboard (HSE, 2008)**

- **WELL PREDICTED!!**

- **M\(_{NF}\) modeled > M\(_{NF}\) real work environment**

CONCLUSIONS

✓ We have models and tools for human risk assessment
✓ Validation and demonstration in real exposure scenarios is needed
✓ STATUS: All parameters requested by models have been described and sources of data identified.
  o Largest number of exposure studies available: SiO₂>TiO₂>Ag>Cu-based
  o Only recent studies take into account most of the parameters requested by HRA models
  o Typical missing parameters: emission rates, dustiness, ventilation, physico-chemical properties
  o Some clear gaps of knowledge: end-of-life stages
✓ Particle levels are fairly well predicted under aerosol modeling (Nanosafer and "standard" two-box model)

RESEARCH NEEDS:
• High quality measurement data for model testing is needed!!
• Harmonized data libraries
ACKNOWLEDGEMENTS

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THANK YOU VERY MUCH FOR YOUR ATTENTION!

*Contact: agf@nrcwe.dk