Stoffenmanager Nano Version 1.0: A Web-Based Tool for Risk Prioritization of Airborne Manufactured Nano Objects

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Stoffenmanager Nano (version 1.0) is a risk-banding tool developed for employers and employees to prioritize health risks occurring as a result of exposure to manufactured nano objects (MNOs) for a broad range of worker scenarios and to assist implementation of control measures to reduce exposure levels. In order to prioritize the health risks, the Stoffenmanager Nano combines the available hazard information of a substance with a qualitative estimate of potential for inhalation exposure. The development of the Stoffenmanager Nano started with a review of the available literature on control banding. Input parameters for the hazard assessment of MNOs were selected based on the availability of these parameters in, for instance, Safety Data Sheets or product information sheets. The conceptual exposure model described by Schneider et al. (2011) was used as the starting point for exposure banding. During the development of the Stoffenmanager Nano tool, the precautionary principle was applied to deal with the uncertainty regarding hazard and exposure assessment of MNOs. Subsequently, the model was converted into an online tool (http://nano.stoffenmanager.nl), tested, and reviewed by a number of companies. In this paper, we describe the Stoffenmanager Nano. This tool offers a practical approach for risk prioritization in exposure situations where quantitative risk assessment is currently not possible. Updates of this first version are anticipated as more data become available in the future.

Keywords: control-banding tool; exposure assessment; hazard assessment; manufactured nano objects; nanoparticles; precautionary principle; risk management

INTRODUCTION

Exposure to manufactured nano objects (MNOs) is an emerging concern in occupational risk assessment and management. Currently, the assessment of possible health risks as a result of exposure to nanoparticles is associated with significant uncertainties. Results from toxicity studies suggest potential specific adverse health effects, such as inflammation and genotoxicity (Oberdörster et al., 2005, 2007; Borm et al., 2006; Buzea et al., 2007). However, knowledge gaps are large and the pace of toxicological testing and exposure research cannot match the pace of development of new nano objects. A comprehensive risk assessment of just the particles currently on the market will take decades. Nevertheless, nanoparticles are produced and handled in an increasing number of occupational settings. As a result, a large population of workers is
potentially at risk. In the Netherlands, the use of the precautionary principle was indicated by the Government in order to minimize exposure to nanoparticles and their release into the environment as low as reasonably achievable, as long as the health risks of working with these materials are uncertain. Control banding strategies are tools that offer simplified guidance to minimize risks for these workers. This qualitative guidance is based on the combination of the hazard of a substance and the potential exposure for the work situation (Zalk and Nelson, 2008).

Presently, there are a limited number of control-banding tools regarding exposure to nanoparticles available (Maynard, 2007; Höck et al., 2008; Wardak et al., 2008; Genaidy et al., 2009; Zalk et al., 2009; ANSES, French agency for food, environmental and occupational health and safety, 2010; Kristensen et al., 2010). Stoffenmanager Nano (in both English and Dutch language) is a risk-banding tool developed for employers and employees handling MNOs. The tool is developed as a first step in the risk assessment, which can be followed by implementation of control measures or a more thorough investigation of the potential risks. To derive the risk prioritization category, the Stoffenmanager Nano combines the available hazard information of a substance with an estimate of inhalation exposure. Stoffenmanager Nano is the nano-specific module within the generic Stoffenmanager risk-banding tool.

The development of the Stoffenmanager Nano started with a review of the available literature regarding control banding strategies for employees working with nanoparticles (Maynard, 2007; Höck et al., 2008; Wardak et al., 2008; Zalk and Nelson, 2008; Zalk et al., 2009; Genaidy et al., 2009; ANSES, French agency for food, environmental and occupational health and safety, 2010; Kristensen et al., 2010) and additional literature regarding hazard and exposure assessment of working with nanoparticles. The precautionary principle was applied to deal with the uncertainty regarding hazard and exposure assessment of MNOs. Input parameters for the hazard assessment of MNOs were selected based on the availability of these parameters in, for instance, Safety Data Sheets (SDSs) or product information sheets. The conceptual exposure model described by Schneider et al. (2011) and the generic Stoffenmanager exposure model were used as the starting point for exposure banding.

Stoffenmanager Nano version 1.0 is freely available as a module within the web-based generic Stoffenmanager risk-banding tool (www.stoffenmanager.nl or directly via http://nano.stoffenmanager.nl). The tool is an evolving system and subsequent versions incorporating new information on exposure and hazard are foreseen in the coming years.

**APPLICABILITY DOMAIN**

As the Stoffenmanager Nano is developed to help employers and employees with limited occupational health and safety experience to prioritize exposure situations involving activities with MNOs, information needed for the use of the tool should be accessible and understandable by the user. To improve the accessibility and understandability of the tool, the tool was tested and reviewed by the companies whereby specific attention was paid on the workability/user friendliness of the tool. Companies were not asked to make estimations for specific workplace situations.

In line with the ISO definition for nanoparticles (International Organization for Standardization Nanotechnologies, 2008b), primary particles exceeding the nano-range (defined as a size range between 1 and 100 nm in at least one dimension) are outside the applicability domain. Within Stoffenmanager Nano, agglomerates and aggregates (independent of diameter) are considered as clusters of MNOs. As clusters could possibly retain nano-specific properties or fall apart in individual MNOs, agglomerates and aggregates are within the applicability domain of Stoffenmanager Nano. For agglomerates and aggregates, surface area presumably gives a better indication for nano-specific properties than particle size. Therefore, Stoffenmanager Nano applies to those substances that consist of MNOs with a primary size between 1 and 100 nm and/or to products with a specific surface area of \( \geq 1/(p) \) \( 60 \text{ m}^2 \text{ g}^{-1} \) (SCENIHR, 2010).

Possible worker exposure situations in the life cycle of nano products are distinguished in four general source domains (Schneider et al., 2011):

1. **Point or fugitive emission during the production phase prior to harvesting the bulk material (e.g. leaks through connections, seals, etc. during MNO synthesis/incidental release; examples of production processes are flame pyrolysis and chemical vapor condensation);**
2. **Handling and transfer of bulk powdered MNOs (e.g. bagging or dumping of powder);**
3. **Dispersion of (solid or liquid) intermediates or ready-to-use MNO-containing products (e.g. spraying, pouring liquids);**
4. **Activities resulting in fracturing and abrasion of MNO-containing end products (e.g. sanding of surfaces).**
Stoffenmanager Nano aims to be applicable for all possible worker exposure situations, although some limitations exist. Firstly, literature regarding exposure modeling of nanofibers and nanotubes is scarce and the effect of the so-called ‘modifying factors’ on exposure for these particles is not clear (Schneider et al., 2011). Consequently, currently it is not possible to model exposure for fiber-like particles on a well-grounded basis. However, irrespective of the assigned exposure band, use of nanofibers will, due to their high hazard potential (asbestos-like carcinogenic effects after inhalation), always result in the highest (risk) priority band (irrespective of the exposure band). In the future, when more information on exposure to nanofibers and nanotubes becomes available, the possibility of including these particles in the exposure model should be explored.

Secondly, currently there are no strong indications that detached MNOs are being released during fracturing and abrasion scenarios for matrix-embedded MNOs in end products (fourth source domain ‘Activities resulting in fracturing and abrasion of MNO-embedded end products’) (Bello et al., 2009; Vorbau et al., 2009; Koponen et al., 2011). Consequently, for exposure scenarios within this source, domain users will be redirected to the generic Stoffenmanager. However, as the decision is based on preliminary results, the consequences should be evaluated in more detail in the future.

GENERAL FRAMEWORK OF STOFFENMANAGER NANO

Stoffenmanager Nano consists of a hazard and exposure banding system and these bands are combined in a risk matrix. These elements are discussed below.

Hazard banding approach

For hazard banding in the generic Stoffenmanager, a classification system based on R or H-phrases is being used (Brooke, 1998; Marquart et al., 2008). Because toxicological data of MNOs are generally lacking (no R-phrases derived for the nanomaterial), alternative (physicochemical) parameters are needed as input for the hazard banding approach for Stoffenmanager Nano.

Several hazard banding approaches for MNOs have been described in literature, albeit with different objectives. The categorization of subsequent risk of these approaches has been related to human health effects associated with MNO exposure at the workplace, potentially hazardous production processes or environmental/life-cycle considerations. These subsequently vary both in complexity and in nature. Parameters that have been used for hazard banding approaches are those that are generally associated with hazardous properties of MNOs: e.g. particle diameter and length, morphology, (water) solubility, degree of agglomeration, bioavailability, (surface) reactivity, catalytic activity, and composition. In addition, characteristics may be based on its parental material, such as its classification and labeling (Paik et al., 2008; Wardak et al., 2008; Giacobbe et al., 2009; Tervonen et al., 2009; Groso et al., 2010).

The most important criteria for parameters used in the risk-banding tool are (i) a clear relationship with the potential hazard of MNOs and (ii) good availability and accessibility of the information. As the information available to Stoffenmanager Nano users on some of the above parameters is very limited, a more pragmatic stepwise approach is applied. This stepwise approach is described in detail below and schematically illustrated in Fig. 1.

**Step 1: water solubility.** The first step within the hazard banding in Stoffenmanager is determining whether the MNO is soluble in water or not. Persistence is generally associated with a low water solubility (<0.1 g l⁻¹; Oberdörster, 2002), whereas MNOs that have a high water solubility are generally considered as low-priority MNOs since nano-specific properties are expected to be lost when particles are in solution (which does not imply that these MNOs cannot be toxic; however not specifically related to their nano-size). When particles are considered to be soluble in biological media, the user is redirected to the generic Stoffenmanager. Water solubility is used as surrogate parameter for solubility in biological media as the latter parameter will generally not be available for Stoffenmanager Nano users. Most MNOs, however, are expected to be insoluble, and this is generally specified in the SDS or product information sheet. Therefore, this criterion determines whether use of Stoffenmanager Nano is appropriate. In case water solubility is not known, the MNO is considered non-soluble.

**Step 2: discrimination of persistent nanofibers.** The subsequent step in the hazard banding approach is the distinction of persistent nanofibers, which are defined as (insoluble) nanofibers exceeding a length of 5000 nm, with the other two dimensions in the nano-size range. Concern has been raised for asbestos-like carcinogenic effects after inhalation of fiber-shaped insoluble MNOs (Poland et al., 2008). This concern is based on the paradigm that all insoluble fibers thinner than 3 μm and longer than 20 μm are biopersistent in the lungs and therefore highly hazardous (Donaldson, 2009). Although the exact hazard for
fiber-like MNOs has not yet been established, the severity of the potential health effect and the uncertainty with respect to the presence of a relevant threshold warrants the classification of persistent nanofibers in the highest hazard category (E). It might not always be possible for a company to identify fiber-like MNOs based on available (product) information (i.e. aspect ratio and/or particle length may not be specified). MNOs are treated as nanofibers in Stoffenmanager Nano only when there is an indication for fiber-like properties (either in size range or nomenclature). When no information is available, MNOs are considered non-fibers. As the absence of specific information for fibers will lead to misclassification, it should be emphasized to the user (and therewith to the manufacturer of the MNO) that information on size and shape of the MNO is essential for an appropriate hazard classification.

**Step 3: classification based on MNO-specific hazard.** For MNOs other than persistent fibers, the hazard indication of the MNO itself should be considered when available. In line with the generic Stoffenmanager, a theoretical categorization ranging from A (practically nonhazardous) to E (non-threshold effects such as sensitization) can be visualized. Because toxicological data are lacking for most MNOs at the moment, this step in the hazard banding approach can be considered a proposal for future use when more nano-specific information on hazard is available. For now, step 3 is presented to the user, who is directed to step 4.

**Step 4: classification based on insufficient toxicological data.** Currently, as no sufficient toxicological data are available for a thorough hazard assessment, hazard banding in Stoffenmanager Nano is either based on the limited data available on the MNO (by using expert judgment) or based on the hazardous potential of its parental material (in case no nano-specific information is available). A list of widely used MNOs has been published by Rijksinstituut voor Volksgezondheid en Milieu (2010), which was based on lists of MNOs reported by the Organisation for Economic Co-operation and Development (OECD) and Borm et al. (2008). These MNOs are assigned to relatively high hazard bands (C through E), depending on current insight (Table 1). Some MNOs, for which specific concern has been raised, have been assigned to the highest hazard band. Crystalline silica/quartz, for instance, has been shown to be much more toxic than the amorphous form (Hazardous Substance Database). Crystalline silica/quartz is therefore assigned to hazard band E and the amorphous...
Table 1. Classification of MNOs in hazard bands based on insufficient toxicological data.

<table>
<thead>
<tr>
<th>Type of MNO</th>
<th>Hazard band</th>
<th>Based on</th>
</tr>
</thead>
<tbody>
<tr>
<td>C60 (fulleranes)</td>
<td>D</td>
<td>Particle-specific data</td>
</tr>
<tr>
<td>Carbon black</td>
<td>&gt;50 nm: C; ≤50 nm: D</td>
<td>Parent material and (limited) particle-specific data</td>
</tr>
<tr>
<td>Ag (nano silver)</td>
<td>&gt;50 nm: C; ≤50 nm: D</td>
<td>Parent material and (limited) particle-specific data</td>
</tr>
<tr>
<td>Fe (iron)</td>
<td>&gt;50 nm: C; ≤50 nm: D</td>
<td>Parent material and (limited) particle-specific data</td>
</tr>
<tr>
<td>Au (gold)</td>
<td>&gt;50 nm: C; ≤50 nm: D</td>
<td>Parent material and (limited) particle-specific data</td>
</tr>
<tr>
<td>Pb (lead)</td>
<td>E</td>
<td>EPA Carc. B2; probable human carcinogen</td>
</tr>
<tr>
<td>La (lanthanide)</td>
<td>&gt;50 nm: C; ≤50 nm: D</td>
<td>Parent material and (limited) particle-specific data</td>
</tr>
<tr>
<td>TiN (titanium nitride)</td>
<td>&gt;50 nm: C; ≤50 nm: D</td>
<td>Parent material and (limited) particle-specific data</td>
</tr>
<tr>
<td>TiO2 (titanium dioxide)</td>
<td>&gt;50 nm: C; ≤50 nm: D</td>
<td>Parent material and (limited) particle-specific data</td>
</tr>
<tr>
<td>CeO2 (cerium oxide)</td>
<td>&gt;50 nm: C; ≤50 nm: D</td>
<td>Parent material and (limited) particle-specific data</td>
</tr>
<tr>
<td>ZnO (zinc oxide)</td>
<td>&gt;50 nm: C; ≤50 nm: D</td>
<td>Parent material and (limited) particle-specific data</td>
</tr>
<tr>
<td>SiO2 (silica or silicon dioxide)</td>
<td>Unknown: E; crystalline/quartz: E; amorph., ≤50 nm: D; amorph., &gt;50 nm: C</td>
<td>Particle-specific data; crystalline silica/quartz has been associated with carcinogenicity (IARC)</td>
</tr>
<tr>
<td>Al2O3 (aluminum oxide)</td>
<td>&gt;50 nm: C; ≤50 nm: D</td>
<td>Parent material and (limited) particle-specific data</td>
</tr>
<tr>
<td>FeO (iron oxides)</td>
<td>&gt;50 nm: C; ≤50 nm: D</td>
<td>Parent material and (limited) particle-specific data</td>
</tr>
<tr>
<td>Sb2O5 (antimony oxide)</td>
<td>E</td>
<td>Parent material classified as Carc Cat 3; R40</td>
</tr>
<tr>
<td>SnO2 (tin oxide)</td>
<td>&gt;50 nm: C; ≤50 nm: D</td>
<td>Parent material and (limited) particle-specific data</td>
</tr>
<tr>
<td>CoO (cobalt oxide)</td>
<td>E</td>
<td>Parent material labeled R43</td>
</tr>
<tr>
<td>Nanoclay</td>
<td>&gt;50 nm: C; ≤50 nm: D</td>
<td>Parent material and (limited) particle-specific data</td>
</tr>
<tr>
<td>Nano-polystyrene</td>
<td>&gt;30 nm: C; ≤50 nm: D</td>
<td>Parent material and (limited) particle-specific data</td>
</tr>
<tr>
<td>Other MNOs</td>
<td>MNOs containing several parent materials; most critical hazard band; parent material unknown: E; parent material classified for C, M, R, or S: E; not classified for C, M, R, or S: D</td>
<td></td>
</tr>
</tbody>
</table>

EPA = Environmental protection agency; Carc. = carcinogen; IARC = International Agency for Research on Cancer.

form to hazard band D. Other MNOs on the list of widely used MNOs are assigned to a hazard band based on the hazard of the parental material. For instance, lead and antimony oxide are suspected carcinogens and the associated nano-form is therefore assigned to hazard band E, from a precautionary point of view.

For MNOs that are widely used, partly characterized, and the parental material is not classified as CMR, hazard band D or C is proposed dependent on the particle size. Hazard band C applies when the primary particle diameter >50 nm and hazard band D when the primary particle diameter ≤50 (Table 1). This additional—arbitrary—size criterion has been introduced to take into account the likelihood of nano-specific health effects. It can be hypothesized that reactivity of MNOs approaching the upper non-nano-size range would be comparable with their bulk counterparts, whereas their
reactivity increases with a reduction in primary particle size. Furthermore, deposition in the lungs is generally higher for smaller particles. It remains to be determined whether an actual cutoff value exists; however, at this moment, it appears rational to introduce an arbitrary cutoff value to account for potential differences between MNOs in the lower nano-range and those approaching the micro-size. Importantly, the attribution to either C or D is rather conservative compared to that applied for the generic Stoffenmanager. Category D can be compared with the sub-maximum score that was attributed to parameters for which data were lacking in the Paik model (Paik et al., 2008).

MNOs other than specified in the Rijksinstituut voor Volksgezondheid en Milieu (RIVM) list (Table 1) are often MNOs for which very limited information is available and are therefore ranked solely according to their parental material. These MNOs are attributed to relatively high hazard categories compared to the generic Stoffenmanager. MNOs are assigned to hazard band E when their parental material is classified for carcinogenicity, mutagenicity, reproduction toxicity, or sensitization. In all other cases, hazard band D is applied. If the parental material is not specified, hazard band E is assigned for precautionary purposes. In appendix 1, a worked example is presented to clarify the banding approach in Stoffenmanager Nano.

**Exposure banding approach**

The underlying model of Stoffenmanager Nano is based on the conceptual model for occupational inhalation exposure to MNOs described by Schneider et al. (2011). The model describes a stepwise transfer of an MNO from the source via various transmission compartments to the receptor (i.e. the worker). Nine modifying factors are incorporated in the model related to source emission, transmission, and immission. These modifying factors are as follows: substance emission potential, handling (activity emission potential), localized controls, segregation, dilution/dispersion, personal behavior, separation (personal enclosure), surface contamination, and respiratory protective equipment. All the modifying factors are described in more detail below.

Schneider et al. (2011) described coagulation and scavenging as important transport processes. Nanoparticles emitted prior to harvesting may coagulate rapidly during the transport to the receptor as nanoparticles have the tendency to coagulate to each other or background particles (scavenging; Luther, 2004; Ma-Hock et al., 2007; Seipenbusch et al., 2008; Schneider and Jensen, 2009). These transport processes influence the number concentration and size of particles and should therefore be included in any exposure model that expresses exposure to nanoparticles in these metrics. However, for a risk-banding tool, these processes are not relevant as the exposure score does not have a metric. In later versions of the Stoffenmanager Nano, where the output of the exposure might be expressed as number concentration and/or particle size, coagulation and scavenging might be included dependent on the needed accuracy and type of user expertise as in this case these processes influence the output.

**Exposure model.** The Stoffenmanager Nano exposure model is used to categorize scenarios in relative exposure bands. The underlying model of Stoffenmanager Nano, the conceptual model described by Schneider et al. (2011), is based on the same source–receptor approach as for the generic Stoffenmanager. The relative exposure score underlying the exposure bands within Stoffenmanager Nano are derived by multiplication of relative multipliers (on a logarithmic scale) for the various modifying factors using the same exposure algorithm as used for the generic Stoffenmanager (Marquart et al., 2008):

\[
B = \left( C_{nf} + C_{ff} + C_{ds} \right) \cdot \eta_{imm} \cdot \eta_{ppe} \cdot t_h \cdot f_h
\]

and

\[
C_{nf} = E \cdot H \cdot \eta_{lc, nf} \cdot \eta_{gv, nf},
\]

\[
C_{ff} = E \cdot H \cdot \eta_{lc, ff} \cdot \eta_{gv, ff},
\]

\[
C_{ds} = E \cdot a,
\]

where \( B \) = exposure score (arbitrary units); \( t_h \) = multiplier for duration of the handling; \( f_h \) = multiplier for frequency of the handling; \( C_{ds} \) = background concentration (score) due to diffusive sources; \( C_{nf} \) = concentration (score) due to near-field sources; \( C_{ff} \) = concentration (score) due to far-field sources; \( \eta_{imm} \) = multiplier for the reduction of exposure due to control measures at the worker; \( \eta_{ppe} \) = multiplier for the reduction of exposure due to use of personal protective equipment; \( E \) = intrinsic emission multiplier; \( a \) = multiplier for the relative influence of background sources; \( H \) = handling (or task) multiplier; \( \eta_{lc, nf} \) = multiplier for the effect of local control measures; \( \eta_{lv, ff} \) = multiplier for the effect of general ventilation in relation to the room size on the exposure due to near-field sources; and \( \eta_{lgv, ff} \) = multiplier for the effect of general ventilation in relation to the room size on the exposure due to far-field sources (Marquart et al., 2008).

This exposure algorithm distinguishes ‘near-field’ [in the breathing zone (<1 m) of the worker]
emissions from ‘far-field’ (the remainder of the work area) emissions because a source of emission that is relatively far from the worker has a lower influence on the worker’s personal exposure than a source very close to the worker.

The exposure algorithm gives two separate prioritizations for personal exposure to offer insight in the risk prioritization between different tasks within a company:

- An event-based risk prioritization based on the exposure during an event;
- A yearly-based risk prioritization, where weighing for exposure intensity, duration, and frequency/occurrence of a task is included in the prioritization. This results in a risk prioritization for working 40 h a week on a yearly basis.

Below, the modifying factors within Stoffenmanager Nano are described for the source, transmission, and immission compartments. In Appendix 1, a worked example is presented to clarify the banding approach in Stoffenmanager Nano.

**Source: Intrinsic substance emission potential**

For source domain 1 ‘production phase’, it is assumed that emission potential does not vary between different types of MNO for the same process. Therefore, the substance emission potential is included in the multiplier for handling and not further included in the algorithm.

The weight fraction (It is used as an indication of the mole fraction. Asking for the weight fraction is a simplification needed for the tool to be easy to use.) of MNOs in the product is a parameter of exposure relevant for all types of products that could be used (powders, granules/flakes, and MNOs in liquids). The exact percentage of MNOs in the product has to be indicated by the user (if unknown, a range can be chosen; Table 2) and is believed to be linearly related to emission potential.

When handling a powdered material (source domain 2 or 3), the key parameter for intrinsic emission potential is dustiness (Schneider et al., 2011). A distinction is made between nanopowders [A nanopowder is defined as a powder consisting of particles with a primary particle size smaller than 100 nm and/or a specific surface area (SSA-BET) larger than (1/p) 60 m² g⁻¹] and granules/flakes [A granule is defined as a specified particle size of 2–4 mm. A flake is defined as a flat thin piece or layer, a chip, or solids with a high concentration of nanoparticles in the matrix] (Tables 3 and 4). Unfortunately, for most, if not all, nanopowders, the quantitative dustiness is not known at present. In addition, potential indicators for dustiness, e.g. physicochemical properties or other characteristics as indicated in product information sheets, e.g. specific surface area, are not studied in detail yet to relate these to substance emission potential. Until dustiness of nanopowders can be included in a quantitative way, it is decided that the highest dustiness class will be given as default for nanopowders to comply with the precautionary principle. If the quantitative dustiness of the powder is known, the user will be able to select a lower dustiness category when applicable. For granules/flakes, two categories are defined based on the intrinsic emission potential of granules in the generic Stoffenmanager (Marquart et al., 2008).

### Table 2. Stoffenmanager Nano multipliers for weight fraction (table adapted from Marquart et al., 2008).

<table>
<thead>
<tr>
<th>Category</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undiluted</td>
<td>1</td>
</tr>
<tr>
<td>55–99%</td>
<td>0.75</td>
</tr>
<tr>
<td>10–50%</td>
<td>0.3</td>
</tr>
<tr>
<td>1–10%</td>
<td>0.05</td>
</tr>
<tr>
<td>0.01–1%</td>
<td>0.005</td>
</tr>
<tr>
<td>&lt;0.01%</td>
<td>0.00005</td>
</tr>
</tbody>
</table>

### Table 3. Stoffenmanager Nano multipliers for dustiness of powders.

<table>
<thead>
<tr>
<th>Category</th>
<th>Indicative dustiness test result (respirable fraction)</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high</td>
<td>&gt;500 mg kg⁻¹</td>
<td>1</td>
</tr>
<tr>
<td>High</td>
<td>150–500 mg kg⁻¹</td>
<td>0.3</td>
</tr>
<tr>
<td>Medium</td>
<td>50–150 mg kg⁻¹</td>
<td>0.1</td>
</tr>
</tbody>
</table>

### Table 4. Stoffenmanager Nano multipliers for dustiness of granules/flakes (table adapted from Marquart et al., 2008).

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granules/flakes</td>
<td>Granules or flakes that may fall apart and crumble</td>
<td>0.03</td>
</tr>
<tr>
<td>Firm granules/flakes</td>
<td>For example, firm polymer granules, granules covered with a layer of wax, bound fibers; no dust emission without intentional breakage of the product</td>
<td>0.01</td>
</tr>
</tbody>
</table>
In addition to weight fraction and dustiness, the moisture content of the product is an important parameter for the intrinsic emission of solids (Fransman et al., 2011). The categories for moisture content are given in Table 5. The substance emission potential of solid MNOs (source domains 2 and 3) is given by the multiplication of the multipliers for dustiness, weight fraction, and moisture content.

For MNOs dispersed in a liquid (source domain 3), the substance emission potential is the multiplication of the scores for the following parameters: weight fraction of the MNOs, percentage dilution of the substance in water, and viscosity of the liquid product (Fransman et al., 2011; Schneider et al., 2011) (Tables 2, 6, and 7, respectively). The effect of vapor pressure and surface tension of the mixture on exposure to MNOs is unknown. It seems unlikely that nanoparticles will evaporate into the air due to evaporation of the mixture. Nanofilm spraying using spray cans is an exception as the particles are released using relatively high pressure and a high volatile mixture that will evaporate very fast and individual nanoparticles may be released. For this reason, it was decided that for nanofilm spraying the substance emission potential would be included in the activity emission potential (described below). Consequently, nanofilm spraying leads to a higher handling multiplier.

Handling (activity emission potential) Four general source domains are distinguished for the worker exposure situations largely based on a combination of substance and activity emission potential (Schneider et al., 2011). The source domain ‘Release of primary particles during synthesis’ involves (new) production processes that are not described in the handling categories included in the generic Stoffenmanager. It is difficult to define Stoffenmanager multipliers for these processes as the tasks performed mostly concern controlling the (closed) process. During a production process, particles might, for example, be released unintentionally through leaks. Despite the lack of exposure data, conservative relative multipliers are defined for this source domain that is in line with the precautionary principle. Doing this gives the user the opportunity to perform a risk assessment for these processes (Table 8).

With the current knowledge, it is assumed that modeling exposure to MNOs for the source domains ‘Handling and transfer of bulk MNO powders’ and ‘Dispersion of intermediates or ready-to-use MNO-containing products’ (except nanofilm spraying as described above) is very similar to handling of solids and liquids used in the generic Stoffenmanager as nanoparticles are agglomerated/aggregated during these handlings. In order to cover the full range of handlings with nanoparticles, some categories are added and adjusted (Tables 9 and 10).

The selection of source domain 4 ‘Activities resulting in fracturing and abrasion of MNO-embedded end products’ results in the redirection of the user to the generic Stoffenmanager.

Transmission compartments:

Localized controls in close proximity of the source intend to remove emissions, e.g. local exhaust ventilation or airborne capture sprays. The assumption is made that the effectiveness to reduce exposure concentrations is similar for nanoparticles and conventional particles. However, very limited data have been generated to prove this (Schneider et al., 2011). Many control measures are described and investigated in the

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**Table 5. Stoffenmanager Nano multipliers for moisture content for solids.**

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry product (&lt;5% moisture content)</td>
<td>Dry powder or granules/flakes</td>
<td>1</td>
</tr>
<tr>
<td>5–10% moisture content</td>
<td>Powder or granules/flakes of which the particles stick to each other while the dry form is not sticky; less dusty than the dry product.</td>
<td>0.1</td>
</tr>
<tr>
<td>&gt;10% moisture content</td>
<td>Powder or granules/flakes that is/are clearly wet</td>
<td>0.01</td>
</tr>
</tbody>
</table>

**Table 6. Stoffenmanager Nano multipliers for dilution of MNO in water (table adapted from Marquart et al., 2008).**

<table>
<thead>
<tr>
<th>Category</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undiluted</td>
<td>1</td>
</tr>
<tr>
<td>55–99%</td>
<td>0.75</td>
</tr>
<tr>
<td>10–50%</td>
<td>0.3</td>
</tr>
<tr>
<td>1–10%</td>
<td>0.05</td>
</tr>
<tr>
<td>0.01–1%</td>
<td>0.005</td>
</tr>
<tr>
<td>&lt;0.01%</td>
<td>0.00005</td>
</tr>
</tbody>
</table>

**Table 7. Stoffenmanager Nano multipliers for viscosity.**

<table>
<thead>
<tr>
<th>Category</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquids with low viscosity</td>
<td>1.0</td>
</tr>
<tr>
<td>Liquids with medium viscosity</td>
<td>0.3</td>
</tr>
<tr>
<td>Liquids with high viscosity</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 8. Stoffenmanager Nano multipliers for source domain 1.

<table>
<thead>
<tr>
<th>Production process</th>
<th>Description</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flame pyrolysis</td>
<td>Injection of carrier liquids in a flame, where carrier liquids are consumed through combustion and nanoparticles are formed and collected on a filter plate</td>
<td>10</td>
</tr>
<tr>
<td>Mechanical reduction (machining)</td>
<td>Machining (turning, milling) of larger products to create smaller products</td>
<td>3</td>
</tr>
<tr>
<td>Chemical vapor condensation</td>
<td>Synthesis of inorganic materials to create nanomaterials by passing inert gases, hydrogen, and hydrocarbon-containing gases in a tube furnace over catalyst particles deposited on substrates</td>
<td>1</td>
</tr>
<tr>
<td>Laser ablation</td>
<td>Synthesis of nanoparticles by laser ablation in preformed colloids in various solvents (e.g. acetone, methanol, ethylene glycol, water)</td>
<td>0.3</td>
</tr>
<tr>
<td>Wet chemistry (functionalization)</td>
<td>Functionalization of nanomaterials by mixing with a solution that contains desired functional groups and removal of excess chemical by washing with solvents</td>
<td>0.3</td>
</tr>
<tr>
<td>Wet chemistry (synthesis—into solution)</td>
<td>Synthesis of nanoparticles by adding parent solution into solvent solution within a container, stirring the mixture for extended period at temperatures from room level to higher</td>
<td>0.3</td>
</tr>
<tr>
<td>Sintering</td>
<td>Synthesis of metal oxide nanowires by sintering small amounts of metal organic solutions in a quartz tube at high temperatures</td>
<td>0.3</td>
</tr>
<tr>
<td>Mechanical reduction (preparation for imaging)</td>
<td>Preparation of nanomaterial samples for imaging purposes; activities include cutting, slicing, grinding, lapping, polishing, chemical etching, electrochemical polishing, and ion etching</td>
<td>0.1</td>
</tr>
<tr>
<td>Wet chemistry (synthesis—within solution)</td>
<td>Synthesis of nanomaterials (e.g. metal salts with organic polymers in water or solvent) to form a homogeneous solution; additional solutions may also be added further reactions, however the entire process remains wet throughout the product’s creation</td>
<td>0.01</td>
</tr>
</tbody>
</table>

literature (Fransman et al., 2008), though for a risk-banding tool a high level of detail is not needed. The localized controls with relative multipliers are adapted from the generic Stoffenmanager (Marquart et al., 2008) based on new information (Fransman et al., 2011). As gloves boxes and glove bags are used during the handling of MNOs, but this category is not included in the generic Stoffenmanager, this category is adapted to Stoffenmanager Nano with a relative multiplier of 0.001 (Fransman et al., 2011) (Table 11).

Segregation of the source aims to isolate the emission source from the worker by means of material barriers resulting in a decrease of personal inhalation exposure. A segregated area is large enough for the worker to enter (e.g. a separate room within the source). This parameter is not included in the generic Stoffenmanager. A relatively low effectiveness was found for segregation for conventional contaminants (Fransman et al., 2008) and a similar effectiveness is assumed for exposure to MNOs. Including segregation in Stoffenmanager Nano is not proposed as including this parameter in a risk-banding tool will presumably not lead to a more accurate prioritization.

Dilution/Dispersion Natural and mechanical ventilation characteristics determine the dilution of air contaminants through the room, i.e. transport between near-field and far-field zone and eventually far field outside. Within Stoffenmanager Nano, dilution is based on the room volume and the ventilation type. Three categories of ventilation are defined: no general ventilation, mechanical/natural ventilation, and spraying booth. As in most cases the exact
ventilation rate is not known, the categories as defined for the generic Stoffenmanager (Marquart et al., 2008) are used with the addition of guidance when the air changes per hour are known (Table 12). When tasks are performed inside spray cabins, no exposure due to a far-field source is assumed.

**Personal behavior** The key determinants for personal behavior are the location of the source in relation to the worker and the amount of latitude the worker has to interact with the source, e.g. from defined work methods or protocols. Since much effort is given to derive good work practices, e.g. International Organization for Standardization Nanotechnologies (2008a), handling nanomaterials might be more protocolized and thus less prone to personal behavior as compared to handling conventional materials. In addition, the effect of personal behavior is implicitly incorporated in the parameter ‘activity emission potential’. Subsequently, it was decided not to include this parameter within Stoffenmanager as a separate parameter.

**Separation** (or personal enclosure) of a worker is an effective way of worker exposure reduction, although the efficiency decreases and the variation increases substantially for partial separation (Fransman et al., 2008). The same effectiveness for nanoparticles and non-nanoparticles is assumed (Schneider et al., 2008).
Table 11. Stoffenmanager Nano multipliers for localized controls (table adapted from Marquart et al., 2008).

<table>
<thead>
<tr>
<th>Category</th>
<th>Examples</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>No control measures at the source</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Use of a product that limits the emission</td>
<td>Wetting a powder, spraying of water</td>
<td>0.3</td>
</tr>
<tr>
<td>Local exhaust ventilation</td>
<td>Removal of air at the source of the emission; the dangerous substances are captured by an air stream leading them into a hood and duct system</td>
<td>0.3</td>
</tr>
<tr>
<td>Containment of the source</td>
<td>The source is fully contained; however, no local exhaust ventilation is used within the containment</td>
<td>0.3</td>
</tr>
<tr>
<td>Containment of the source with local exhaust ventilation</td>
<td>Containment of the source in combination with local exhaust ventilation, e.g. a fume cupboard</td>
<td>0.03</td>
</tr>
<tr>
<td>Glove boxes/bags</td>
<td>Any form of permanent encapsulation or encasing of the source (which are not opened during the given activity) with a well-designed local exhaust ventilation system</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Table 12. Stoffenmanager Nano multipliers for reduction by general ventilation for near-field (A) and far-field sources (B). The score is given to a combination of room volume in cubic meter and ventilation type. No far-field exposure is assumed in a spraying booth, due to the special conditions in a spraying booth (table adapted from Marquart et al., 2008).

<table>
<thead>
<tr>
<th>Room size (volume)</th>
<th>No general ventilation (0.3–1 ACH)</th>
<th>Mechanical and/or natural ventilation (3 ACH)</th>
<th>Spraying booth (&gt;10 ACH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume &lt;100 m³</td>
<td>10</td>
<td>3</td>
<td>0.1</td>
</tr>
<tr>
<td>Volume 100–1000 m³</td>
<td>3</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td>Volume &gt;1000 m³</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Work performed outside</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume &lt;100 m³</td>
<td>10</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Volume 100–1000 m³</td>
<td>1</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Volume &gt;1000 m³</td>
<td>0.3</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Work performed outside</td>
<td></td>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>

ACH = air changes per hour.

Table 13. Stoffenmanager Nano multipliers for separation (table adapted from Marquart et al., 2008).

<table>
<thead>
<tr>
<th>Category</th>
<th>Examples</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>The worker does not work in a cabin</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>The worker works in a cabin without specific ventilation system</td>
<td>A cabin of a tractor or truck, a cabin not equipped with filters, overpressure system, etc., or behind a screen</td>
<td>0.1</td>
</tr>
<tr>
<td>The worker works in a separated (control) room with independent clean air supply</td>
<td>The workplace of the worker is in a (control) room that is equipped with an air supply system independent of the air in the room where the source is</td>
<td>0.03</td>
</tr>
</tbody>
</table>

2011). Within Stoffenmanager Nano, only categories for total separation are included due to the large variability in the effectiveness for partial separation (Table 13). The difference between separation and segregation is that separation is the enclosure of the worker and segregation is the enclosure of the source.

Surface contamination results in a background emission related to release of deposited contaminants on surrounding surfaces (including worker clothing) due to natural means or general workplace activities (e.g. moving equipment/vehicles). It is assumed that background emission is related to the intrinsic emission, i.e. the multiplier for background sources is multiplied by the intrinsic emission.
by how often machines were inspected and on cleaning practices in the work area (Marquart et al., 2008) (Table 14).

**Receptor:**

**Personal protective equipment** Shaffer and Rengasamy (2009) have reviewed and analyzed the research literature and current recommendations on respirators used for protection against nanoparticles. They concluded that analysis of the reviewed data from studies on laboratory filtration performance, face seal leakage, and total inward leakage suggests that traditional respirator selection guidance should be used until workplace studies can be performed specifically for the efficiency of respirators for protection against nanoparticles, which could serve as the basis for updated recommendations. Subsequently, for Stoffenmanager Nano, the categories regarding personal protective equipment are adopted from the generic Stoffenmanager (Table 15).

**Exposure bands**

After the user has answered the exposure-related questions for each of the modifying factors (described above), the tool will calculate the overall Stoffenmanager Nano exposure score using the described exposure algorithm. The exposure score is not used directly as the score itself is not reflecting a quantitative exposure level and using the scores directly for ranking situations would suggest more precision than can be claimed by a tool like this. The final qualitative exposure score is assigned to an exposure band (1–4) on the logarithmic scale (Table 16).

**Establishment of the risk matrix and assignment of risk-reduction strategies**

The results from the hazard and exposure banding are combined in a risk matrix, which gives the risk priority band (1 = high priority, 2 = medium priority, or 3 = low priority) presented in Fig. 2. The matrix provides priorities based on the hazard of an MNO and level of exposure for different workplace

---

### Table 14. Stoffenmanager Nano multipliers for surface contamination (table adapted from Marquart et al., 2008).

<table>
<thead>
<tr>
<th>Category</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>No regular inspections and maintenance of machines and equipment, no daily cleaning</td>
<td>0.03</td>
</tr>
<tr>
<td>No regular inspections and maintenance of machines and equipment, daily cleaning</td>
<td>0.01</td>
</tr>
<tr>
<td>Regular inspections and maintenance of machines and equipment, no daily cleaning</td>
<td>0.01</td>
</tr>
<tr>
<td>Regular inspections and maintenance of machines and equipment, daily cleaning</td>
<td>0.01</td>
</tr>
</tbody>
</table>

---

### Table 15. Stoffenmanager Nano multipliers for respiratory protective equipment for exposure to dust (table adapted from Marquart et al., 2008).

<table>
<thead>
<tr>
<th>Category</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>1</td>
</tr>
<tr>
<td>Filter mask P2 (FFP2)</td>
<td>0.4</td>
</tr>
<tr>
<td>Filter mask P3 (FFP3)</td>
<td>0.2</td>
</tr>
<tr>
<td>Half-mask respirator with filter, type P2L</td>
<td>0.4</td>
</tr>
<tr>
<td>Half-mask respirator with filter, type P3L</td>
<td>0.2</td>
</tr>
<tr>
<td>Full-face respirator with filter, type P2L</td>
<td>0.2</td>
</tr>
<tr>
<td>Full-face respirator with filter, type P3L</td>
<td>0.1</td>
</tr>
<tr>
<td>Half-/full-face powered air respirator TMP1  (particulate cartridge)</td>
<td>0.2</td>
</tr>
<tr>
<td>Half-/full-face powered air respirator TMP2  (particulate cartridge)</td>
<td>0.1</td>
</tr>
<tr>
<td>Half-/full-face powered air respirator TMP3  (particulate cartridge)</td>
<td>0.1</td>
</tr>
<tr>
<td>Full-face powered air respirator TMP3 (particulate cartridge)</td>
<td>0.05</td>
</tr>
<tr>
<td>Hood or helmet with supplied air system TH1</td>
<td>0.2</td>
</tr>
<tr>
<td>Hood or helmet with supplied air system TH2</td>
<td>0.1</td>
</tr>
<tr>
<td>Hood or helmet with supplied air system TH3</td>
<td>0.05</td>
</tr>
</tbody>
</table>

---

### Table 16. Stoffenmanager Nano exposure bands (table adapted from Marquart et al., 2008).

<table>
<thead>
<tr>
<th>Exposure band</th>
<th>Range</th>
<th>Stoffenmanager Nano scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;0.002</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.002–0.2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.2–20</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>&gt;20</td>
<td></td>
</tr>
</tbody>
</table>

---

**Fig. 2.** Priority bands in the Stoffenmanager. Hazard: A = lowest hazard and E = highest hazard; exposure: 1 = lowest exposure and 4 = highest exposure; overall result: 1 = highest priority and 3 = lowest priority (adapted from Marquart et al., 2008).
situations. The allocation of risk bands has been done to ensure a generally increasing priority with increasing concern for hazard and/or exposure. Similar to the generic Stoffenmanager, Stoffenmanager Nano distinguishes three priority bands because fewer bands would lead to an oversimplified representation of risk, while more bands would suggest more precision than actually present.

The use of MNOs is associated with a high degree of uncertainty. This uncertainty is taken into account in the attribution to certain exposure and hazard bands. Therefore, the risk matrix can be conservative but is similar to that of the generic Stoffenmanager. Allocation into priority bands has been done in such a way that exposure to very high hazardous substances, such as persistent fibers, will lead to a high priority regardless of the exposure band. The intention is to ensure that these substances and their use and control are considered specifically and in more detail on a case-by-case basis by the user. MNOs with an unknown hazardous profile are given a high priority in case they fall into a relatively high exposure band.

In view of the overall uncertainty associated with both hazard and exposure assessment of MNOs, high exposure situations should be avoided and therefore high exposure bands automatically lead to high priority for all hazard categories except category A. It should be emphasized that currently, in view of lack of information, no MNO will be assigned to hazard band A or B. This means that a low-priority band can only be accomplished when the scenario is classified in the lowest exposure band (Fig. 2).

When an exposure scenario is evaluated and a priority band is assigned, Stoffenmanager Nano enables the user to design a risk-reduction scenario. This option provides the user with a list of possible control measures that can be implemented to lower exposure, thus the risk. Subsequently, the exposure situation is automatically prioritized again. Implementing a reduction scenario is advised even though implementation might not directly lead to a lower priority category.

**DISCUSSION**

As quantitative risk assessment for MNOs is not possible yet and MNOs are handled in a wide variety of exposure scenarios resulting in a large population of workers possibly at risk, there is an interest in control banding strategies. Stoffenmanager Nano is such a tool developed to help employers and employees to prioritize exposure situations involving the handling of MNOs. The output of the model, either an event-based risk prioritization or a risk prioritization including weighing factors for duration and frequency/occurrence of a task, provides the user with detailed insight in the risks between different tasks within a company. The tool enables companies to identify high risk situations with a minimal data requirement. Stoffenmanager Nano is intended to be used by employers and employees, so operational quality is of major importance since specific expertise in chemical risk assessment and risk management is expected to be limited. Information needed to use Stoffenmanager Nano should be easily accessible and understandable for the user. Unfortunately, presently, only few toxicological input parameters are available to users as can be obtained from available SDSs and product information sheets. In addition, measurement data are only available to a limited extent. Given these limitations, the Stoffenmanager Nano is based on the state-of-the-art knowledge regarding risk assessment for MNOs. The scientific basis of the tool was discussed during a scientific advisory panel teleconference organized by the Stoffenmanager consortium. The scientific advisory panel consisted of experts in the field of hazard assessment, exposure assessment, and risk assessment.

For a quantitative hazard assessment (i.e. derivation of occupational exposure levels), scientific basis is currently lacking and consequently a pragmatic hazard banding approach has been applied. Hazard bands associated with different levels of severity can be distinguished by introducing ‘weight factors’ for each of the parameters used, as has been proposed by Paik et al. (2008). For the purpose of our hazard banding tool, we find the attribution of hazard bands based on qualitative consideration more suitable in view of transparency (i.e. it provides direct justification for the attribution to a category rather than an arbitrary hazard score). The same approach was followed by ANSES, French agency for food, environmental and occupational health and safety (2010). Our approach partly follows the considerations underlying the benchmark values proposed by BSI (2007) and IFA, by assigning nanofibers and soluble MNOs to specific classes. Furthermore, it shares similarity with the British Standards Institution approach as it takes into account the hazardous properties of the parental material.

Unavoidable, for the development of a pragmatic hazard banding tool, in the absence of specific information the precautionary principle should be taken into account. This is implemented by attributing MNOs to relatively high hazard bands (C, D, or E), whereas most of the parental materials used would normally be assigned to lower hazard bands in the
generic Stoffenmanager. In addition, certain classes of MNOs are strictly assigned to the highest hazard band. Insoluble nanofibers, for instance, are assigned to band E because of the concern for asbestos-like carcinogenic effects after inhalation of fiber-shaped insoluble MNOs. Primarily, its fiber length (i.e. >5000 nm) determines whether it is treated as a persistent fiber in Stoffenmanager Nano (given that the other two dimensions are in the nano-range). Due to this relatively broad definition, it is likely that certain nanofibers that are not associated with persistence and carcinogenic effects are misclassified in hazard band E. However, specific information on these effects is often not available to the user or can only be interpreted by toxicological experts. Also, MNOs of which the parental material has been classified for high priority end points are assigned to hazard band E, emphasizing the need for substituting these classes of chemicals.

The exposure banding in Stoffenmanager Nano is based on a semiquantitative approach by the use of weight factors as quantitative exposure assessment is not possible yet. The exposure banding within Stoffenmanager Nano follows a different approach than the exposure banding in other available control-banding tools for nanoparticles (Maynard, 2007; Höck et al., 2008; Wardak et al., 2008; Zalk and Nelson, 2008, 2009; Genaidy et al., 2009; ANSES, French agency for food, environmental and occupational health and safety, 2010). Within Stoffenmanager Nano, the emission, transmission, and immission are included in the estimation of the exposure, while the other tools only estimate the emission potential of exposure. As transmission and immission (e.g. local controls) are included in Stoffenmanager Nano, the outcome of the model is more a risk prioritization instead of a real control banding that gives a control approach as output.

For this first version of Stoffenmanager Nano, the scientific basis regarding different parameters of exposure was limited. For example, for activity emission potential and dustiness, scientific data is scarce. Consequently, the inclusion of these parameters was for a large part based on expert judgment, taking the precautionary principle into account. New categories were added where needed to cover for the full range of activities. Scores for these new categories follow a logarithmic scale in line with the generic Stoffenmanager.

The transport processes coagulation and scavenging are not included in this version of Stoffenmanager Nano. These transport processes influence the number concentration and size of particles and should therefore be included in any exposure model that expresses exposure to nanoparticles in these metrics (Schneider et al., 2011). Yet, for an exposure banding tool, these processes are not relevant as the exposure score does not have a metric. In later versions of the Stoffenmanager Nano, where the output of the exposure might be quantified, e.g. expressed as number concentration and/or particle size, coagulation and scavenging should be included because these processes can influence the output. The transport processes may only be relevant for activities within source domain 1 ‘production phase’ and the activity ‘nanofilm spraying’ as during these activities potentially primary particles may be released at relatively high concentrations, in contrast with release in other source domains.

For many modifying factors of exposure to MNOs, it was assumed that their effect on exposure is similar as for conventional particles. Future exposure measurements, in experimental and workplace settings, should confirm that the assumptions made are true. Unfortunately, measuring exposure to nanoparticles is very complex (e.g. due to issues related to background exposure, different measurement instruments available, choice of exposure metric) and there is no consensus about the measurement strategy at this moment. So, even though the need for measurement data is large, to get more insight in exposure to MNOs and for the development of a quantitative model, it is unlikely that in the near future a large amount of data will become available.

As discussed in this paper, Stoffenmanager Nano is developed to be an easy-to-use tool for situations in which specific data are lacking. As a result of this, the estimates of potential health risks are characterized by a high degree of uncertainty. This uncertainty is much larger than that in risk assessments involving traditional chemicals. Because of this current high degree of uncertainty, the developers of Stoffenmanager Nano have chosen a qualitative assessment of the possible health risks. The expectation is that in coming years, the knowledge about possible risks of nanoparticles will increase substantially, allowing a more scientifically justified hazard and exposure assessment. In future versions of Stoffenmanager Nano, this new information will be included to better underpin and refine the input for different parameters. Hence, release of this first version allows timely decisions on worker protection based on limited knowledge and simultaneously facilitates an incremental reduction of this uncertainty for the long term; in addition, it is anticipated that subsequent updated versions will be less conservative.
APPENDIX 1: WORKED EXAMPLE ‘BAGGING OF IRON POWDER’

To clarify the algorithm and the multipliers in the mechanistic model, we present a worked example, ‘bagging of iron powder’ with average particle size of 25 nm. There is one operator active at the bagging station, the task being carried out in the breathing zone. Demonstrable and effective housekeeping practices are in place. No information on dustiness and moisture content is stated on the material safety data sheet (MSDS). The product is described as being irritating to the eyes and the respiratory system (R36/37). The duration of the task is 0.5–2 h/day with a frequency of 4–5 days/week. The work is performed indoors (room size 100–1000 m³) with mechanical ventilation in the workroom and local exhaust ventilation at the source being present. No respiratory protective equipment is used. The table below shows the relevant parameters for each of the modifying factors in the mechanistic model and the accompanying multipliers.

<table>
<thead>
<tr>
<th>Modifying factor</th>
<th>Relevant parameter</th>
<th>Description</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity emission potential</td>
<td>Source domain: handling of bulk aggregated/agglomerated nanopowders</td>
<td>Activity: handling of products with a relatively high speed/force that leads to dispersion of dust</td>
<td>30</td>
</tr>
<tr>
<td>Substance emission potential</td>
<td>Dustiness</td>
<td>Unknown</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Moisture content</td>
<td>Unknown</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Weight fraction</td>
<td>Pure product</td>
<td>1</td>
</tr>
<tr>
<td>Localized controls</td>
<td>Local exhaust ventilation</td>
<td></td>
<td>0.3</td>
</tr>
<tr>
<td>Dilution/dispersion</td>
<td>Room volume 100–1000 m³</td>
<td>Mechanical ventilation</td>
<td>1</td>
</tr>
<tr>
<td>Separation</td>
<td>The worker does not work in a cabin</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Surface contamination</td>
<td>Demonstrable and effective housekeeping practices</td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td>Personal protective equipment</td>
<td>None</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Frequency of the task</td>
<td>4–5 days/week</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Duration of the task</td>
<td>0.5–2 h/day</td>
<td></td>
<td>0.25</td>
</tr>
</tbody>
</table>

Applying the equations of the model results in an exposure score of 9.01 during the task and 2.2525 as time- and frequency-weighted score. Based on these scores, exposure band ‘3’ is assigned.

\[
B = \left[ \left( \frac{C_{nf}}{C_{ds}} \right) + \left( \frac{C_{ff}}{C_{inf}} \right) + (C_{ds}) \right] \cdot \eta_{imm} \cdot \eta_{ppe} \cdot h \cdot f_h
\]

\[
B = \left[ (9) + (0) + (0.01) \right] \cdot 1 \cdot 1 \cdot 0.25 \cdot 1 = 2.2525
\]

and

\[
C_{nf} = E \cdot H \cdot \eta_{hc_nf} \cdot \eta_{gv_nf}
\]

\[
C_{inf} = (1 \cdot 1 \cdot 1) \cdot 30 \cdot 0.3 \cdot 1
\]

\[
C_{ff} = E \cdot H \cdot \eta_{hc_ff} \cdot \eta_{gv_ff}
\]

\[
C_{ff} = 0 \text{ (no farfield exposure)}
\]

\[
C_{ds} = E \cdot a
\]

\[
C_{ds} = (1 \cdot 1 \cdot 1) \cdot 0.01
\]

\[
E = \text{weight fraction} \cdot \text{dustiness} \cdot \text{moisture content}
\]

Based on the information on the MSDS, the substance could not be classified in one of the hazard bands; as specific hazard data for the nanoparticle are not available, the R-phrases most likely apply to the parent material. Therefore, classification of iron powder based on insufficient toxicological data leads to a classification in band D (Table 1; OECD list of substances and particle diameter < 25 nm). Combining hazard and exposure class results in a risk score of ‘1’ both for the activity during the task as for the time- and frequency-weighted activity.
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