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TNO Report

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Stoffenmanager Nano: Description of the conceptual control banding model

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1 Introduction

1.1 Control banding

Worker inhalation exposure to Manufactured Nano Objects (MNOs) is an emerging issue in occupational risk assessment and management. Results from toxicity studies suggest potential specific adverse health effects. However for a wide range of exposure situations data are lacking. In the absence of dose-response relationships and exposure data, presently a quantitative risk assessment is not possible for worker inhalation exposure to MNO.

Control banding (CB) strategies offer simplified qualitative solutions for controlling worker exposures when there is an absence of firm toxicological and exposure information or knowledge. Within most existing CB strategies it is a generic technique to prioritize occupational situations based on bands reflecting:

- The likelihood of exposure to the particles,
- Their potential hazard (such as skin/eye irritant, very toxic, carcinogenic, etc), and
- A band of exposures (low, medium, high exposure), possibly taking into account control measures (for example dilution ventilation, engineering controls, containment, etc.) (NIOSH, 2009).

For a CB tool intended to be used by small and medium-sized enterprises (SME), operational quality and user friendliness is of major importance since specific expertise in chemical risk assessment and risk management is often lacking. A number of features are critical:

- The concept should be understandable. The user and those who are affected by the output of the approach should understand the concept. This is of importance for communication of the outcome of the approach.
- Information required by the CB tool should be available to the user. This will help to ensure that the schemes are capable of being implemented with a minimum of expert training or specialized resources. It also means that they can be more readily used in areas where the availability of expert skills or resources is poor, e.g. within SMEs.
- The tool should be fitted to the needs of the user. Important features are: type of language used, needed skills and background knowledge, user friendliness (easy-to-use), deliver practical advice.
- The tool should be transparent and should produce consistent output (Money, 2003).

In this document the development of a qualitative 'control banding' tool (Stoffenmanager Nano) for prioritizing the potential human health risks caused by worker inhalation exposure to MNOs is described. Different aspects of the control banding tool are discussed during a Scientific Advisory Panel (SAP) telecom (SAP, 2010). Experts from the field of exposure and risk assessment of MNOs were invited for a panel to give feedback to the Stoffenmanager consortium. This feedback is used to further develop the model.

Incorporating Stoffenmanager Nano within the Stoffenmanager tool has the main advantage that Stoffenmanager is a well-known tool to prioritize risks and quantitatively assess exposure used by almost 12,000 people. Presently, Stoffenmanager is one of the tools that can be used for worker inhalation exposure assessment within the scope of the Chemical Agents Directive (CAD) REACH. At this moment, REACH does not specifically addresses the risk assessment of MNOs, however, in the future MNOs probably will fall within the scope of REACH. Developing Stoffenmanager Nano will help companies to meet future legislation with the CAD REACH. The first version of the Stoffenmanager Nano (to be released in the beginning of 2011) is aimed to be a tier 1 tool for prioritizing risks. In the future, the tool might be further developed to a tool for quantitative risk assessment.

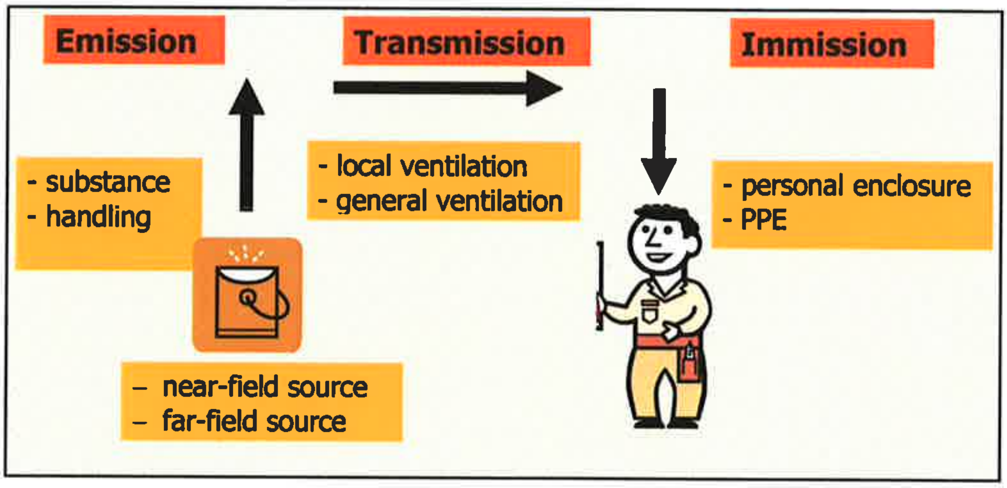
To come to a conceptual model for Stoffenmanager Nano the available literature regarding CB of MNOs was reviewed. Subsequently, the conceptual model was discussed by a science advisory board and national stakeholders.

1.2 Stoffenmanager: an introduction

Stoffenmanager is a webbased tool developed to help SME to prioritize exposure situations to hazardous substances at the workplace and assist to implement control measures. Strictly speaking, Stoffenmanager is a risk banding tool which enables an iterative process to evaluate the impact of control measures on the risk category. The tool is used by both experts and non-experts within the field of occupational hygiene. Within this chapter a short description of Stoffenmanager is given. For a more detailed description of the model we refer to Marquart *et al.* (2008) and Tielemans *et al.* (2008a) and Schinkel (2010). The tool is freely available (in English and Dutch) online via www.stoffenmanager.nl.

Stoffenmanager is developed for risk assessment of personal event-based exposure levels for workers. The heart of Stoffenmanager is a risk banding strategy. Within this strategy a hazard banding scheme similar to that of COSHH Essentials and an exposure banding scheme based on an exposure model originally presented by Cherrie *et al.* (1996) and further developed by Cherrie and Schneider (1999) are combined.

The exposure model described by Cherrie *et al.* (1996) and Cherrie and Schneider *et al.* (1999) has been modified to enable non-expert users to understand and use the model. The exposure algorithm follows a source-receptor approach and incorporates modifying factors related to source emission and dispersion of contaminants. Exposure is represented as a multiplicative function of substance emission potential, activity emission potential, near-field and far-field sources, reduction of transmission (local controls and general ventilation), reduction of immission and the background. Below, a short description of the modifying factors and their categories included in the Stoffenmanager inhalation exposure model are given.



- Substance emission potential. The starting point is a (classified and labelled) chemical product, of which the user should indicate if it is handled in solid or liquid form. In case of the handling of a liquid the vapour pressure and concentration are needed to estimate the substance emission potential. In case of the handling of a solid a dustiness category (solid objects, firm granules or flakes, granules or flakes, coarse dust, fine dust, extremely dusty products) should be chosen.

- Activity emission potential. The type of activity (handled amount is included in the description) should be chosen from a list of categories for both handling of liquids or solids. The type of activities are related to a number of processes which can be described in physical-chemical terms, such as frictional forces. that may influence emission.

- Near-field and far-field sources. A source of emission that is relatively far located from a worker has a lower influence on the exposure of the worker than the same source very closely located to the worker. Cherrie and Schneider (1999) have therefore distinguished the ‘near-field’ emissions, which take place very close to the worker, from the ‘far-field’ emissions that occur further away form the worker. A near-field source is defined as a source within 1 meter of the head of the worker. A far-field source is more than 1 meter from the head of the worker. A source is made recognizable to users by asking whether exposure takes place in the breathing zone (<1 meter), or whether other workers in the room are doing the same task. In addition the user is asked whether there is a period of evaporation, hardening or drying of products on a surface that is left in the work area of the worker. The far-field exposure is calculated by multiplying the near-field source with a correction factor for general ventilation in the far-field. Near-field and far-field source are included separately in the exposure algorithm.

- Reduction of transmission. Reduction of transmission from the source towards the worker is possible in several ways. In Stoffenmanager this is split in the two factors local control (containment of the source with LEV, containment of the source, LEV, Use of product that limits the emission, no control measures) and room ventilation (natural ventilation, mechanical ventilation or spraying booth in relation to the size of the workroom (volume < 100 m^3, 100-1000m^3, > 1000 m^3 or work is performed outside)). The reduction factors of room ventilation are different for the near field and far field sources.

- Reduction of immission. Reduction of immission could be obtained by separating the worker from the source and by the use of personal protective equipment (PPE). Three categories of personal enclosure of the worker are defined (the worker is in a separated (control) room with independent clean air supply, the worker works in a cabin without specific ventilation system, the worker does not work in a cabin).

Thirteen categories regarding PPE for exposure to dust and seven categories regarding PPE for exposure to liquids are defined.

- Background emission. Background emissions e.g. by re-suspension, are based on information about the substance used, the existence of a far-field and contamination of the workroom or equipment obtained by the following questions:

  -Is the workplace cleaned daily?

  -Are inspections and maintenance of machines/ancillary equipment being done at least monthly to ensure good condition and proper functioning and performance?

- Duration and frequency. The Stoffenmanager prioritizes separate tasks with products, based on the exposure related to the product and the task and the hazards related to the products. Some tasks may be performed only parts of the total work shift. This is accounted for by modification of the exposure score based on duration of the task during a working day and frequency of the task (year based). The calculated exposure score is based on the assumption that a task is being performed during 8 hours a day with a frequency of 5 days per week (40 hours per week). In this situation, the factor 'duration times frequency of task' is 1. If a task is being performed during fewer hours per day and/or in a lower frequency than 5 days per week, a linearly proportional reduction of the factor duration times frequency of task is used.

The combination of the exposure bands and hazard bands leads to a risk band. This is a deviation from other control banding strategies, like COSHH Essentials, that result in a control band, which gives a user direct advice on the control strategy to be used. Although Stoffenmanager is strictly speaking not a control banding tool, it does enable the user to design a risk reduction scenario or control scenario based on the assigned priority band and the control measures already used.

The first versions of Stoffenmanager were developed to prioritize worker health risks by a qualitative, relative ranking within a company. In later versions (including the current version 4.0) of Stoffenmanager the exposure model within Stoffenmanager was calibrated with measured occupational hygiene data to derive a quantitative inhalation exposure assessment model (Tielemans *et al.* 2008a). The Stoffenmanager inhalation exposure model was subsequently validated with approximately 250 exposure measurements (Schinkel *et al.*, 2010).

1.3 Stoffenmanager Nano: applicability domain

Stoffenmanager Nano is aimed to be applicable for all types of MNOs. Currently, the definition of a "nano object" is still under debate. ISO (ISO/TS 27687, 2008) described the following definition for nano objects: 'material with one, two or three external dimensions in the nanoscale'. Within this document, a nanoparticle is defined as a nano-object with all three external dimensions in the nanoscale, a nanoplate is defined as a nano-object with one external dimension in the nanoscale and a nanofiber is defined as a nano-object with two similar external dimensions in the nanoscale and the third dimension significantly larger.

For the development of Stoffenmanager Nano we choose to use the definition described by ISO, and made some additional remarks regarding the applicability domain:

- The particle should be intentionally produced or manufactured;

- Regarding powders: Primairy particle size should be smaller than 100 nm, and / or the specific surface area should be larger than 60 m^2/g (SCENIHR, 2010).
- Manufactured nano objects may be present as single objects, but may also be present as agglomerates/aggregates. Within Stoffenmanager aggregates and agglomerates are included in the applicability domain. Agglomerate is defined as 'collection of weakly bound (nano-sized) particles or aggregates or mixtures of the two where the resulting external surface area is similar to the sum of the surface areas of the individual components. An aggregate is defined as 'a particle comprising strongly bonded or fused particles where the resulting external surface area may be significantly smaller than the sum of calculated surface areas of the individual components' (ISO/TS 27687, 2008).

Presently, different types of MNOs are used within SME. The types of MNOs used include: Carbon black, fumed Silica, amorphous Silica, Silica nanospheres, Aluminium oxides, Titanium dioxide, Cerium oxide, Zinc oxide, quantum dots, ferric oxide, Silver particles, Cobalt oxide, Lanthanide, Ggld, Antimony oxide; tubes/fibres such as Carbon nanotubes (single-walled and multi-walled) and plates, *e.g.* clays.

MNOs are used within a large variety of exposure situations. Stoffenmanager Nano should ideally be applicable for all these situations. Four general source domains are distinguished *i.e.*:

1 Release of primary particles during actual synthesis *e.g.* fugitive emissions through valves, pipe connections, mechanical seals, or related equipment.

2 Handling of bulk aggregated/ agglomerated nanopowders (*e.g.* bagging, dumping, handling contaminated bags),[1]

3 Spraying or dispersion of a ready-to-use nanoproduct (*e.g.* spray application with aerosol formation),

4 Fracturing and abrasion of MNOs-embedded end products (*e.g.* blending object, grinding surfaces) (Schneider *et al.*, 2011).

It is not clear whether Stoffenmanager Nano could be applicable for all types of MNOs and all four source domains, as it is not clear if all information on both exposure and hazard needed for a CB tool is available for all types of particles and source domains. With the current knowledge, it is assumed that modelling exposure to MNO for source domains 2 and 3 is very similar to modelling exposure to inhalable particles and/or liquid aerosols. Regarding source domain 4 the available literature indicates that exposure to nanoparticles is not possible. Consequently, the user will be redirected to the generic Stoffenmanager to perform the risk inventory. Using worst-case default values for missing information could substantially extend the applicability domain and is in line with the precautionary principle. Of course, this has to be clearly communicated with the user and the user should re-analyse an exposure situation in case information becomes available.

[1] We make the assumption that during the handling all primary particles readily agglomerate/aggregate and that no exposure to primary particles can occur. We realize that part of the released particles will remain as free particles or becomes free again. For now we do not consider free particles during this source domain. As for example deposition of individual particles is different from agglomerates and this will affect exposure, this should be mentioned to the user (SAP, 2010).

2 Banding of exposure

2.1 Review of the literature - exposure banding parameters

A limited number of peer reviewed papers is available regarding exposure banding, of which the most important are presented and discussed in appendix 1. The parameters included in the exposure banding are described and compared to the exposure banding within Stoffenmanager 4.0.
Within Stoffenmanager the following parameters of exposure are included:
- Substance
- Handling
- Near-field and far-field
- Local controls
- Dispersion
- Personal enclosure
- PPE
- Background exposure
- Duration
- Frequency

Review of literature regarding exposure banding resulted in the following possible additional parameters of exposure:
- New product (Wardak *et al.*, 2008)
- Disposal pathways (Wardak *et al.*, 2008)
- Stability of coating (Wardak *et al.*, 2008)
- Particle size < 200 nm (Wardak *et al.*, 2008)
- High aspect ratio (Wardak *et al.*, 2008)
- Media-dependent properties (Wardak *et al.*, 2008)
- Used in conjunction with other products (Wardak *et al.*, 2008)
- Number of employees (Zalk *et al.*, 2008, 2009)

'New product' and 'disposal pathways' are parameters not included in Stoffenmanager. Within the model described by Wardak *et al.* (2008) 'new product' is described as a risk based on the assumption that most information on new products will be unknown. The uncertainty associated with new products can be captured during the hazard band determination. The number of 'disposal pathways' is according to Wardak *et al.* (2008) an important parameter in the assessment of inhalation exposure to MNO as more pathways result in a higher probability of exposure. Disposal pathways address what happens after the MNOs are handled and not what happens during worker exposure. Consequently, disposal pathways are not included in Stoffenmanager Nano.

The parameters 'stability of the coating', 'particles size < 200 nm' and 'high aspect ratio' are parameters more relevant for hazard banding than for exposure banding and are therefore not included in the exposure banding within Stoffenmanager. These parameters are considered for hazard banding as described in the next chapter.

'Media-dependent properties' and 'used in conjunction with other products' are indirectly included in Stoffenmanager within the parameter 'substance emission potential'. No further attention is given to these parameters, as substance emission potential is included in the exposure model.

Zalk *et al.* (2008, 2009) included the 'number of employees' as a probability factor. If more workers perform a task then the probability of exposure is higher. Up to now the parameter 'number of employees' has not been included in Stoffenmanager, for the reason that Stoffenmanager assigns a risk priority to an event or to a year-weighted event for an individual worker. If more workers are performing the same task at the same time then the other worker(s) than the worker for which the risk assessment is performed, are included in the far-field exposure. Stoffenmanager does not make a distinction in the number of workers in the far-field, so there could be 1 worker in the far-field or 100 workers in the far-field leading to the same far-field exposure estimate in Stoffenmanager.

2.2 Review of the literature - additional exposure banding parameters

Schneider *et al.* (2011) have developed a conceptual model for assessment of inhalation exposure to MNO to give a framework for future exposure models. Basically, the conceptual nano model follows the same structure as the conceptual model for inhalation exposure which is used within Stoffenmanager and the Advanced REACH Tool (ART) (Marquart *et al.*, 2008, Tielemans *et al.*, 2008b; Fransman *et al.*, 2009). The conceptual nano model includes the following additional parameters of exposure compared to Stoffenmanager:

- Personal behaviour
- Coagulation/ scavenging
- Segregation

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

'Coagulation and scavenging' are transport process parameters not included in Stoffenmanager 4.0. Manufactured nano-objects emitted prior to harvesting may coagulate rapidly during the transport to the receptor as nano-objects have the tendency to agglomerate (Luther, 2004; Ma-Hock *et al.*, 2007; Seipenbusch *et al.*, 2008; Schneider and Jensen, 2009; Brouwer *et al.*, 2009). Consequently, a nano-model for exposure should take into account:

- Coagulation of MNOs emitted from a production line or reactor prior to harvesting by both homogeneous coagulation between MNOs and heterogeneous coagulation or scavenging by background or associated larger particles;
- The degree to which the agglomerates in bulk nanopowder will break by shear forces during handling and the consequences for the size distribution and structure (morphology) of the particles released to the air.

The influence of coagulation and scavenging is however only relevant for the source domain 'release of primary particles during synthesis'. Including coagulation and scavenging is probably less relevant for the other source domains *i.e.* 'Handling of bulk aggregated/ agglomerated MNOs product' and 'spraying or dispersion of a ready-to-use nanoproduct' except during application of nano film sprays. This should be indicated to the user. In addition, coagulation and scavenging will affect or will be affected by the parameters: dispersion, background concentration and effectiveness of localized controls, segregation, personal enclosure and PPE.

The complex influence of electric and magnetic dipoles, turbulence and external force fields on coagulation and scavenging are very difficult to include in an easy-to-use model like Stoffenmanager Nano. Consequently, this parameter is not included in the first version of Stoffenmanager Nano. The user should be informed that inclusion of coagulation and scavenging was not possible although the effect on exposure probably is very important for various exposure scenarios. During the Stoffenmanager Nano Scientific Advisory Panel (SAP) telephone conference (SAP, 2010) the SAP agreed that coagulation and scavenging should not be included in Stoffenmanager Nano version 1.0, as this is impossible at this moment. In the future this parameter should be added when more information becomes available, but inclusion of this parameter will depend on the amount and availability of information needed by the user.

'Segregation', (complete or partial) of the source from the work environment, is a parameter that could result in a decrease of personal inhalation exposure. A relatively low effectiveness was found for this control measure for conventional contaminants (Fransman *et al.*, 2008). The effectiveness of segregation for MNOs is assumed to be similar to conventional particles, however experimental data are missing (Schneider *et al.*, 2011). Segregation is not included in Stoffenmanager 4.0. Including segregation in Stoffenmanager Nano is not proposed as including this parameter in a control banding tool will presumably not lead to a more accurate prioritization. The SAP (SAP, 2010) agreed that segregation should not be included in Stoffenmanager Nano as no added value of including the parameter was foreseen for a risk prioritization tool.

2.3 Exposure banding algorithm within Stoffenmanager Nano

As the conceptual model described by Schneider *et al.* (2011) is based on the same underlying conceptual source-receptor-approach (Cherrie *et al.*, 1996; Cherrie and Schneider, 1999) of Stoffenmanager, it seems reasonable to use this approach for the exposure banding for MNOs within Stoffenmanager Nano (For more details regarding the conceptual model we refer to appendix 1). A major difference between the conceptual model described by Schneider *et al.* (2011) and Stoffenmanager is the simplification of the far-field within Stoffenmanager. Within Stoffenmanager it is assumed that the same activity is conducted using the same substance in the far field as in the near field. How the far field is included in Stoffenmanager is shown in the Stoffenmanager exposure algorithm:

$$B = [(C_{nf}) + (C_{ff}) + (C_{ds})] * \eta_{imm} * \eta_{ppe} * t_h * f_h$$
$$C_{nf} = E * H * \eta_{lc\_nf} * \eta_{gv\_nf}$$
$$C_{ff} = E * H * \eta_{lc\_ff} * \eta_{gv\_ff}$$
$$C_{ds} = E * a$$

Where B = exposure score; t_h = duration of the handling; f_h = 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; η_{imm} = multiplier for the reduction of exposure due to control measures at the worker;

η_{ppe} = multiplier for the reduction of exposure due to use of personal protective equipment; E = intrinsic emission score; a = multiplier for the relative influence of background sources; H = handling (or task) score; η_{lc} = multiplier for the effect of local control measures; η_{gv_nf} = multiplier for the effect of general ventilation in relation to the room size on the exposure due to near-field sources and η_{gv_ff} = multiplier for the effect of general ventilation in relation to the room size on the exposure due to far-field sources.

As stated before, the first version of Stoffenmanager Nano will be a qualitative control banding tool. Subsequently, the model gives a first rough indication of likelihood of exposure. Including the far-field in more detail, as is done for the mechanistic model described by Fransman *et al.* (2009), could give the impression to the user that the model is over precise. In addition to inclusion of the far-field in more detail, Schneider et al (2011) defined more categories for some parameters of exposure (compared to Stoffenmanager) based on the literature available on these parameters. Finally, segregation is not included in the Stoffenmanager algorithm.

In summary, we propose to use the algorithm described for Stoffenmanager 4.0 for Stoffenmanager Nano 1.0. The categories proposed for the different parameters are described in the next section.

We propose that Stoffenmanager Nano will give two separate risk bands as output:
- An event-based risk prioritization
- A risk prioritization including weighing for duration and frequency/occurrence of a task. This result in a risk prioritization for working 40 hours a week year based.

Both outcomes are priorities based on personal exposure. E.g. more workers performing the same task at the same time are not included in the prioritization. The only difference between the output for the event-based risk prioritization and the prioritization including weighing for duration and frequency/occurrence of a task is the inclusion of the parameters duration and frequency. Inclusion of these two outputs provides the user more detailed insight in the risks between different tasks within a company.
The scores for the categories of duration and frequency/occurrence are presented below. These tables are copied from Stoffenmanager 4.0 (BECO, 2008). The SAP (SAP, 2010) agrees with this approach.

Table 1 presenting scores for duration of tasks

Description	Score
4 to 8 hours a day	1
2 to 4 hours a day	0.5
0.5 to 2 hours a day	0.25
1 to 30 minutes a day	0.06

Table 2 presenting scores for frequency of tasks

Description	Score
4 to 5 days a week	1
2 to 3 days a week	0.6
Approximately 1 day a week	0.2
Approximately 1 day per 2 weeks	0.1
Approximately 1 day a month	0.05
Approximately 1 day a year	0.01

The differences between the two different outputs can be presented by an example. When a task is only performed 2.5 hours a day and 1 day a week then the Stoffenmanager score for the event should be multiplied by 0.50 * 0.20.

Within the model described by Zalk *et al.* (2008, 2009) it is possible to score a parameter when the information is unknown. In these cases the user chooses the category ‘unknown’ for a parameter and the given score is 75 % of the highest score for the parameter. Consequently, the model can be used when information is lacking. For some of the parameters included in Stoffenmanager Nano this approach might also be applicable. This approach is not desirable for all parameters, as a minimum of information should be available to perform a risk assessment. The use of defaults in cases where the user is not able to give a score, will be described for a parameter when this is appropriate.

2.4 Categorization of parameters and discussion

Below the proposed categorization of the parameters for the Stoffenmanager Nano model are described. The classification of parameters described below are mainly based on the Stoffenmanager 4.0 classification (BECO, 2008) and on additional information described by Schneider *et al.* (2011).

First the user has to determine if the particles handled (dispersed in a liquid or not) are MNOs or embedded MNOs. The user should check if the MNO complies with the definition defined for Stoffenmanager. In case a user does not handle a MNO the user should be redirected to Stoffenmanager 4.0.

The user should indicate if the substance that is handled is a MNO based on the following criteria:

- Any structure (object) that is composed of discrete functional parts, which have one or more external dimension in the nano-scale (particles (defined as a nano-object with all three external dimensions in the nanoscale), fibres (defined as a nano-object with two external dimensions in the nanoscale), or plates (defined as a nano-object with one external dimension in the nanoscale)).
- Manufactured nano objects may be present as single objects, but may also be present as agglomerates/aggregates. Within Stoffenmanager aggregates and agglomerates are included in the applicability domain. Agglomerate is defined as ‘collection of weakly bound (nano-sized) particles or aggregates or mixtures of the two where the resulting external surface area is similar to the sum of the surface areas of the individual components. An aggregate is defined as ‘a particle comprising strongly bonded or fused particles where the resulting external surface area may be significantly smaller than the sum of calculated surface areas of the individual components’ (ISO/TS 27687, 2008).
- The particle should be intentionally produced or manufactured;
- The particles should be insoluble.
- Regarding nanopowders: Primairy particle size should be smaller than 100 nm, and/or the specific surface area (SSA-BET) should be greather than or equal to (1/ρ) 60 m^2/g.

If the criteria above are met the user is able to start the risk prioritization using Stoffenmanager Nano. Otherwise, the user is redirected to the generic Stoffenmanager.

Source
Activity emission potential. Determines the intrinsic emission potential of an activity. The user has to indicate to which of the four source domains the activity included in the assessment is assigned. Most source domains are a combination of substance and activity emission potential. The source domains are:

1 Release of primary particles during actual synthesis, *e.g.* fugitive emissions through valves, pipe connections, mechanical seals, or related equipment. This type of emission can be considered specific for the type and operational conditions of the synthesis process. We assume this is the only source domain where exposure to primary MNOs is possible.

2 Handling of bulk aggregated/agglomerated nanopowders, *e.g.* bagging, dumping, handling contaminated bags.[2] A nanopowder is a powder consisting of agglomerates and/ or aggregates[3] of primary manufactured objects smaller than 100 nm and a specific surface area (SSA-BET) greather than or equal to (1/ρ) 60 m^2/g. We assume the powders handled are aggregates/agglomerates, subsequently exposure modelling is assumed to be very similar to conventional particles.

3 Spraying or dispersion of a ready-to-use nanoproduct, *e.g.* spray application with aerosol formation, handling granules. These activities involve two main types of down-stream-uses of MNOs:

- Spraying of ready-to-use nano products (e.g. nanosprays, nano coatings). **Ready-to-use nano products** are defined as liquid dispersions of manufactured primary nanoscale particles with relatively low concentrations (usually smaller than 0.1 % (w/w)), where no further processing is required prior to use/ application. During spraying a dispersed free MNO might result in the release of free MNOs aerosol.
- Handling of granulated or liquid intermediates containing MNOs. The handling of granules primarily involves the step before the start of a hot process in which a ready-to-use granule is processed in a product. **Intermediates** are defined as a liquid (paste/slurry) or a solid (thermoplastic (master batch)) that are highly concentrated (usually ≥ 10% (w/w)) dispersions of MNOs, which require further processing/ dilution.

4 Fracturing and abrasion of MNOs-embedded end products, *e.g.* activities included processing (*e.g.* sanding, grinding) of solid products with manufactured primary nanoscale object dispersed and fixed within a matrix) (Schneider *et al.*, 2011).

After selecting a source domain, the user has to choose a handling category based on the product handled. The handling categories for the products handled are described below for each source domain.

Source domain 1: The source domain 'release of primary particles during synthesis' involves (new) production processes that are not described in the handling categories included in Stoffenmanager 4.0 (BECO, 2008). It is difficult to define scores for these processes as the task performed mostly concerns controlling the system. During the

[2] We make the assumption that during the handling all primary particles readily agglomerate/aggregate and that no exposure to primary particles can occur. We realize that part of the released particles will remains as free particles or becomes free again. For now we do not consider free particles during this source domain. As for example deposition of individual particles is different from agglomerates and this will affect exposure, this should be mentioned to the user (SAP, 2010).
[3] Part of the nano powder will remain as free particles or will become free again. For simplicity we assume that all particles in the powder will be aggregated/ agglomerated product.

process particles will be released unintentionally from the ractor, connections, valves etc. In addition, during most of the process heat is used which also results in production of other nanoparticles that are not of interest. At this moment it is very difficult to define the particles that are released during a process in time as the online measurement equipment is not able to characterize particles.

The conceptual nano exposure model (Schneider *et al.*, 2011) is not intended to be applicable for nanofibers and nanotubes within the source domain 'release of primary particles during synthesis'. However, Stoffenmanager Nano is intended to be applicable for nanofibers and nanotubes. The possibility of including nanofibers and nanotubes and how these particles could be included in a model should be explored. For now, nanofibres and nanotubes are included without any problems, as the hazard band for these particles will (in the current version) always result in the highest priority band. In the future including these particles should be studied in more detail.

For source domain 1 the following handling categories are defined:

Synthesis Operation Type	**Example Activity Description**	**Score**
Flame Pyrolysis	Injection of carrier liquids in a flame, where carrier liquids are consumed through combustion and nanoparticles are formed and collected on a filter plate.	10
Mechanical Reduction (Machining)	Machining (turning, milling) of larger products to create smaller products.	3
Chemical Vapor Condensation	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 a substrates.	1
Laser Ablation	Synthesis of nanoparticulates by laser ablasion in preformed colloids in various solvents (e.g. acetone, methanol, ethylene glycol, water).	0.3
Wet Chemistry (Functionalization)	Functionalization of nanomaterials by mixing with a solution that contains desired functional groups and removal of excess chemical by washing with solvents.	0.3
Wet Chemistry (Synthesis – into solution)	Synthesis of nanoparticles by adding parent solution into solvent solution within a container, stirring the mixture for extended period at temperatures from room level and higher.	0.3
Sintering	Synthesis of metal oxide nanowires by sintering small amounts of metal organic solutions in a quartz tube at high temperatures.	0.3
Mechanical Reduction (Preparation for Imaging)	Preparation of nanomaterial samples for imagining purposes. Activities include cutting, slicing, grinding, lapping, polishing, chemical etching, electrochemical polishing and ion etching.	0.1
Wet Chemistry (Synthesis – within solution)	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	0.01

	process remains wet throughout the product's creation.	

Source domain 2 and 3: For the source domains 'handling and transfer of bulk MNO-powders' and 'spraying ready-to-use MNO-containing products' the conceptual model can be applied for all particles. For these source domains the handling categories included in Stoffenmanager 4.0 described for solids and liquids are proposed for Stoffenmanager Nano. Some new categories are added so the full range of activities involving the handling of MNOs could be assessed using Stoffenmanager Nano. The examples given for the categories in Stoffenmanager 4.0 are adapted to tasks involved in the handling of MNOs and amounts used are more specified.

Categories for handlings of solids (powder/granules/flakes)

Category	**Examples**	**Score**
Handling of products, where due to high pressure, speed or force large quantities of dust are generated and dispersed	Spraying of powders (powder coating), dumping of product from big bags, cleaning of contaminated machines or object with compressed air.	100
Handling of products with a relatively high speed/force which leads to dispersion of dust	Bagging of large quantities of product, mechanical mixing or sieving of large quantities of product.	30
Handling of products with medium speed or force, which leads to some dispersion of dust.	Manual dumping of bags, machanical mixing or sieving of medium quantities of product.	10
Handling of products with low speed or little force, which leads to some dispersion of dust.	Sweeping of product. Manual mixing or sieving of product. Uncontrolled handling of objects that are heavility contaminated with product.	3
Handling of products with low speed or little force or in medium quantities (several kilograms).	Handling of contaminated objects. Scooping of (kilograms) product. Weighing of products (kilograms).	1
Handling of products in small amounts (up to 100 gram) or in situations where only low quantities of products are likely to be released.	Weighing of 100 gram product. Transport of containers with light contamination.	0.3
Handling of products in closed containers	Transport/shifting of barrels, bottles or plastic bags.	0

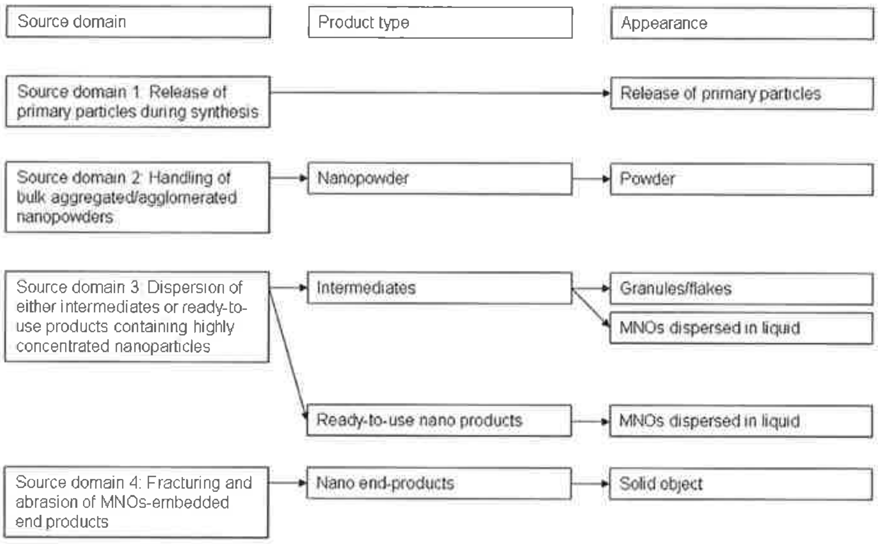
Categories for handlings of liquids (nanoparticles dispersed in liquids)

Category	Examples	Score
Handling of liquids at high pressure resulting in substantial generation of visible mist or spray/haze	Spraying of product (using high pressure or spray painting), fogging of product producing a visible mist. Spraying of Nanofilm spray.	30
Handling of liquids (using low pressure, but high speed) resulting in generation of a mist or spray/haze	Mixing of products under high velocity using a mixer, uncontrolled pouring of a liquid from a large altitude.	3
Handling of liquids using low pressure, low speed with large or medium quantities.	Mixing/diluting of liquids by stirring, manually drawing off or pouring of product, painting of casings using a roller or brush.	0.1
Handling of (almost) undisturbed liquids (very low speed), very small quantities (under controlled conditions) of liquids in tightly closed containers.	Transport/shifting of containers with liquid. Pipetting small quantities of liquid under laboratory conditions.	0

Source domain 4: For the source domain 'fracturing and abrasion of nanoparticles-embedded end products' the characteristics of the material handled are changed due to the inclusion of MNOs in the matrix. At this moment there are no indications in the literature that individual MNOs will be released during fracturing and abrasion of nanoparticles-embedded end products (Bello et al., 2009; Koponen et al., 2010; Vorbau et al., 2009). The literature indicates that the MNOs stay embedded. The user will be redirected to Stoffenmanager 4.0 to perform a risk prioritization for the other substances in the product.

Activities including hot processes (like melting granules during compounding or moulding) are not included in this version of Stoffenmanager Nano as the available literature is very limited. As hot processes are relevant for the handling of MNOs, these processes should be added in Stoffenmanager Nano in the future (when more knowledge will be available).

Substance emission potential determines the intrinsic emission potential of an agent. After selecting the source domain and handling category the user is, depending on the source domain chosen and physical state of the product, directed to questions regarding substance emission. The flow scheme below presents the options between source domain, product type and appearance.



Flow scheme presenting options source domains, product type and appearance.

Source domain 1 is the only source domain where exposure to primary particles is expected. In case this source domain is selected the user will directly be directed to the near field /far field question. No questions regarding substance emission potential will be asked.

The mole/weight fraction of MNOs in the product is a parameter of exposure relevant for all types of products that could be used (powders, granules/flakes and liquids). The exact percentage of MNOs in the product should be indicated by the user. In case the user does not know the exact percentage, the user should choose one of the categories described in the following table. If no percentage is given than 100 % MNOs will be used as default.

Scores for mole/weight fraction in product (Fransman *et al.* (in progress)).

Category	**Score**
Pure product (100%)	1.0
Main component (50-99%)	0.75
Substantial (10-50%)	0.3
Small (1-10%)	0.05
Very small (0.01-1%)	0.005
Extremely small (<0.01%)	0.00005

Powder

For nano powders the key parameter for substance emission is dustiness (Schneider *et al.*, 2011). Ideally, we would like to include the quantitative dustiness of a substance. Unfortunately, for most, if not all, nanopowders the dustiness is not known at present. In addition, physico-chemical properties or other characteristics as indicated in Product Information Sheets, *e.g.* specific surface area that could be indicators/ determinants for dustiness are not studied in detail to relate these to substance emission potential. More dustiness test results of nano powders and alternative dustiness categories, and possibly metrics are needed (Schneider *et al.* (2011)). Pensis *et al.* (2010) compared the results of dustiness tests of industrial minerals using the two dustiness test methods described in EN 15051: the rotating drum and continuous drop method. EN 15051 (CEN, 2006)

presents a classification system to express the dustiness of a product. Probably, more information will be available in the near future as different institutes are working on dustiness research. When new information becomes available this should be included in Stoffenmanager Nano.
Until dustiness of MNOs can be included in a quantitative way, from a practical point of view it is decided that the highest dustiness class will be given as default. If the user knows the exact dustiness of the powder, then the user is able to select a lower dustiness category when applicable based on this dustiness test result.

The table below presents the proposed classification scheme for dustiness categories in case no quantitative dustiness is available.

Scores for dustiness of powders

Category	**Indicative dustiness test result (respirable fraction)**	**STM score**
Very high	> 500 mg/kg	1
High	150-500 mg/kg	0.3
Medium	50-150 mg/kg	0.1

In addition to dustiness and weigth fraction of MNOs in the product the moisture content is important (Fransman *et al.*, 2009). The categories for moisture content are given in the table below.

Categories for moisture content (Fransman *et al.* (in progress)).

Category	**Description**	**STM score**
Dry product (< 5% moisture content)	Dry powder.	1
5 – 10 % moisture content	Powder of which the particles stick to each other while the dry powder form is not sticky. Less dusty than the dry product.	0.1
> 10 % moisture content	Powder that is clearly wet	0.01

The SAP (SAP, 2010) agrees with the categories for weight fraction and moisture content. The dustiness categories are under discussion.

Granules and flakes

A granule is defined as a specified particle size of 2–4 millimetres. A flake is defined as a flat thin piece or layer or a chip. Weight fraction of the particulate substance (as described above), dustiness and moisture content are defined as important determinants for the substance emission potential for granules and flakes. The SAP (SAP, 2010) agrees with the categories proposed.

The table below presents the proposed classification scheme for dustiness categories. The category 'granules/flake' will be the default. The user is able to select another category based on the description.

Categories for dustiness (STM 4.0).

Category	**Description**	**STM score**
Granules /flakes	Granules or flakes that may fall apart and crumble. 	0.03
Firm granules/or flakes	For example, firm polymer granules, granules covered with a layer of wax, bound fibers. No dust emission without intentional breakage of the product. 	0.01

The categories for moisture content are given in the table below.

Categories for moisture content (Fransman *et al.* (in progress)).

Category	**Description**	**STM score**
Dry product (< 5% moisture content)	Dry granules/flakes.	1
5 – 10 % moisture content	Granules/flakes of which the particles stick to each other while the dry granule/flake form is not sticky. Less dusty than the dry product.	0.1
> 10 % moisture content	Granules/flakes that are clearly wet.	0.01

Liquids (MNOs dispersed in a liquid)
Fransman *et al.* (2009) defined mole/weight fraction of the particulate substance in the liquid mixture (as described above) and the viscosity as important determinants for

solids dispersed in a liquid. For MNOs dispersed in liquids the same determinants of exposure are assumed to be relevant. The SAP (SAP, 2010) agrees with this assumption.

Within Stoffenmanager the user has to indicate the percentage of a substance in the liquid. In addition the user has to select one of the categories described in the table below if the substance in the liquid is diluted in water. In case the user does not indicate the weight fraction of the particles in a dilution, the Stoffenmanager Nano will use 100 % (undiluted) as default.

Weight fraction categories[4]	Stoffenmanager score
Undiluted	1
50-99%	0.75
10-50%	0.3
1-10%	0.05
0.01-1%	0.005
<0.01%	0.00005

Viscosity is currently not included in Stoffenmanager 4.0. The viscosity of the liquid in which the nanopowder is dispersed has an influence on the exposure (Fransman *et al.*, 2009) and should be included in Stoffenmanager Nano. Liquids with a low viscosity are more prone to become airborne than liquids with a high viscosity. Consequently, exposure to MNOs dispersed in liquids with a low viscosity will result in a higher exposure then when the MNOs are dispersed in a liquid with a higher viscosity. The user should choose the viscosity from the next table:

Classification	Stoffenmanager score
Liquids with low viscosity (like water)	1.0
Liquids with medium viscosity (like oil)	0.3
Liquids with high viscosity (like paste, syrup)	0

The substance emission potential of a powder dispersed in liquid (E_i) is calculated using the following algorithm:
E_i = *% MNOs in undiluted mixture * weight fraction in dilution * viscosity.*

In addition to weight fraction and viscosity, the type of liquid in which the MNOs are dispersed might have a great influence on the potential of exposure. The effect of vapour pressure and surface tension of the mixture on exposure to nanoparticles is unknown. It seems unlikely that nanoparticles will evaporate into the air due to evaporation of the mixture. Nanofilm spraying seems to be an exception, as the particles are released using a high volatile mixture which will evaporate very fast so a layer of individual nanoparticles will be formed. Subsequently, some product characteristics should lead to a high substance emission score. However, for now it is too difficult to include scoring for these characteristics in the substance emission potential. Therefore

[4] Weight fraction 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.

we decided that this will be included in the activity emission potential in a simplified manner. For now, nanofilm spraying will lead to a high handling score. The SAP (SAP, 2010) agreed that some characteristics of the mixture have an effect on the substance emission. For now it was decided that these characteristics should be included in the handling categories in a robust manner.

Near-field / far-field. A source of emission that is relatively far from a worker has a lower influence on the exposure of the worker than a similar source very close to the worker. Cherrie and Schneider (1999) have therefore distinguished the 'near-field' emissions, which take place very close to the worker, from the 'far-field' emissions that occur further away form the worker.

A near-field source is defined as a source within 1 meter of the head of the worker. If the source is more than 1 meter from the head of the worker, then this is a far field source of exposure. For exposure to MNOs other workers performing the same task in the same room are a far-field source. In Stoffenmanager 4.0 another source for far field exposure is possible: a period of evaporation, hardening or drying of products on a surface (after application) that is left in the work area of the worker. For the exposure to MNOs this source is not relevant as MNOs will not evaporate.

Within Stoffenmanager 4.0 the far-field exposure is calculated by multiplying the near-field source with a correction factor for general ventilation in the far-field. Near-field and far-field source are included separately in the exposure algorithm.

The same approach for including near field and far field is included in Stoffenmanager nano. The following questions will be asked:

- Is the task being carried out in the breathing zone of the employee (distance head-product < 1 meter)? Yes or no
- Is there more than one employee carrying out the same task simultaneously? Yes or no

Transmission compartment

Localized control. Control measures in close proximity of the source intended to remove emissions, e.g. local exhaust ventilation, airborne capture sprays. In general, for most precautionary measures, the assumption is made that the effectiveness to reduce exposure concentrations, is similar for manufactured nano-size aerosols, articles and aerosols of conventional particles. However, very limited data have been generated to prove this.

Full enclosure, where the process is completely contained, e.g. glove box, glove bag, are control measures that have shown high efficiency for pharmaceutical powders if the design is such that the enclosure cannot be opened (Fransman *et al.*, 2009).

The overall efficiency of local exhaust ventilation (LEV) systems depends on the degree of enclosure, hood design and air flow, specifications of the contaminant cloud, and operators' activities (HSE, 2008). Particle capture efficiency in a ventilation system is affected by the particle size. Current scientific knowledge indicates that the established criteria for maintenance and use of ventilation systems, e.g. recommended by ACGIH, should be applicable to controlling airborne exposure to nanometer-scale particles at least to the same levels as fine particles (Schulte *et al.*, 2008).

The effectiveness of partial enclosure in combination with ventilation, *e.g.* fume cupboard or fume hood, has been investigated for a few nanopowders during transfer of small to high lab-scale amounts by pouring and scooping (Tsai *et al.*, 2008b). The authors reported in some cases a significant increase of particle number concentration in the breathing zone during handling the MNOs. Effectiveness of the fume hood appeared to be related to fume hood design, sash heights and resulting face velocity, work practices, and turbulent air penetration from the fume hood. Methner *et al.* (2008)

reported for the use of LEV during reactor cleanout operations an overall reduction of particle concentration by LEV of 96% for particles in the size range 300 -10,000 nm, whereas in general the lowest size ranges showed the highest reduction.
More generic figures on local exhaust ventilation (LEV), including enclosure, were reported by Fransman *et al.* (2008) with an estimated overall efficiency of 86% for dusts and vapours. However a large variation was observed. Exterior LEV and mobile LEV show somewhat and much lower overall efficiencies, respectively, and even larger variations.
In case of recirculation of air the effectiveness of filters to intercept MNOs should be demonstrated. In general the filtration efficiency demonstrates a characteristic "U" shape curve as a function of particle size with a minimum filtration efficiency at approximately 350 nm (Hinds, 1999). This particle size is commonly referred as the Most Penetrating Particle Size (MPPS). Smaller particles (10-100 nm) are captured mainly by diffusion and larger particles (1-10μm) by interception and impaction mechanisms (Schulte *et al.* 2008). Pui *et al.* (2008) showed high effectiveness of the recirculation of air filtrated by fibrous filter media on reducing exposure to incidental and intentionally produced airborne MNOs.

More control measures than the control measures mentioned above are available. Fransman *et al.* (2009) have described a detailed list of possible control measures that are available. However, for a control banding tool this level of detail is not needed. All the types of control measures except the use of glove boxes or glove bags and partial containment are described in categories within Stoffenmanager. As glove boxes and glove bags are used during the handling of MNOs this category is proposed to be added to the Stoffenmanager categories. As the variability of the effectiveness of partial containment is very large and because these categories are not included in the generic Stoffenmanager, it is decided that partial containment will not be included in Stoffenmanager Nano. The categories proposed for Stoffenmananger Nano are:

Category	**Description**	**STM score**
No control measures at the source		1
Use of a product that limits the emission	For example, wetting a powder, spraying of water	0.3
Local exhaust ventilation	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	0.3
Containment of the source	The source is fully contained, however, no local exhaust ventilation is used within the containment	0.3
Containment of the source with local exhaust ventilation	Containment of the source in combination with local exhaust ventilation, e.g. a fume cupboard	0.03
Glove boxes/bags	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.	0.001

Dilution / dispersion (near-field and far-field). Natural and mechanical ventilation characteristics, determining the dilution of air contaminants through the room, *i.e.* between NF–FF zone and FF outside. Within Stoffenmanager dilution is based on the room volume and the ventilation type (BECO, 2008). Three categories of ventilation are proposed: no general ventilation, mechanical/natural ventilation and spraying booth. Within Stoffenmanager Nano also a distinction should be made for the near-field, far-field and work performed outside. As in most cases the exact ventilation rate is not known we propose to use the categories as defined for Stoffenmanager 4.0 (BECO, 2008). We have added a range of air changes per hour (ACH) in the description of the categories as additional guidance for the user. When tasks are performed inside spray cabins, it was decided that exposure due to a far-field source was unlikely.

Scores for reduction by general ventilation for near-field sources. The score is given to a combination of room volume in cubic meter and ventilation type. ACH = air changes per hour.

Room size (volume)	No general ventilation (0.3 – 1 ACH)	Mechanical and or natural ventilation (3 ACH)	Spraying booth (> 10 ACH)
Volume < 100 m³	10	3	0.1
Volume 100 – 1000 m³	3	1	0.3
Volume > 1000 m³	1	1	1
Work performed outside	-	1	-

Scores for reduction by general ventilation for far-field sources. The score is given to a combination of room volume in cubic meter and ventilation type. ACH = air changes per hour. No far-field exposure is assumed in a spraying booth, due to the special conditions in a spraying booth.

Room size (volume)	No general ventilation (0.3 – 1 ACH)	Mechanical and or natural ventilation (3 ACH)	Spraying booth (> 10 ACH)
Volume < 100 m³	10	3	-
Volume 100 – 1000 m³	1	0.3	-
Volume > 1000 m³	0.3	0.1	-
Work performed outside	-	0.1	-

Separation. Providing a worker with a personal enclosure within a work environment, e.g. air conditioned cabin. During the activity the enclosure is not opened. Schneider *et al.* (2011) assume the same effectiveness as for 'conventional' exposures. Fransman *et* *al.* (2009) included partial separation in addition to the categories defined for Stoffenmanager 4.0 (BECO, 2008). Separation of a worker is an effective way of exposure reduction, although the efficiency decreases and the variation increases substantially for partial separation (Fransman *et al.*, 2008). For Stoffenmanager Nano we decided not to add the categories described for partial segregation by Fransman *et al.* (2009) to the categories described for Stoffenmanager, due to the large variability. In the future versions of Stoffenmanager Nano this parameter might be added if more information becomes available.

Category		**STM score**
The worker does not work in a cabin		1
The worker works in a cabin without specific ventilation system	For example in a cabin of a tractor or truck, a cabin not equipped with filters, overpressure system etc. or behind a screen	0.1
The worker works in a separated (control) room with independent clean air supply	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	0.03

Surface contamination. 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). In Stoffenmanager 4.0 (BECO, 2008), background emission covers sources such as leaking machinery, contaminated rags left lying around, spills that haven't been cleaned up, etc. It is assumed that background emission is related to the intrinsic emission, i.e. the modifying factor for background sources was multiplied by the intrinsic emission. Intrinsic emission was then modified by a multiplier determined by how often machines were inspected and on cleaning practices in the work area. Within Stoffenmanager 4.0 (BECO, 2008) four categories are defined. The same categories are proposed for Stoffenmanager.

Category	STM score
No regular inspections and maintenance of machines and equipment – no daily cleaning	0.03
No regular inspections and maintenance of machines and equipment – daily cleaning	0.01
Regular inspections and maintenance of machines and equipment – no daily cleaning	0.01
Regular inspections and maintenance of machines and equipment – daily cleaning	0

Personal behavior (near-field). Orientation and distance of the worker to the source in the near-field, determining the potential exposure, e.g. worker positioned at very close distance during precision work, overhead work. Personal behavior is mainly included in the activity emission potential in Stoffenmanager Nano. In addition, the user has to indicate if the task is performed in the near field.

Receptor

Personal protective equipment. Efficiency of respiratory protective equipment preventing the inhalation of airborne substances was not described in the article of Schneider *et al.* (2011). Schneider *et al.* (2011) assume the same effectiveness as for 'conventional' exposures. We propose to include the categories included in Stoffenmanager for Stoffenmanager Nano.

Category	**Score**
Dust	
None	1
Filter mask P2 (FFP2)	0.4
Filter mask P3 (FFP3)	0.2
Half mask respirator with filter, type P2L	0.4
Half mask respirator with filter, type P3L	0.2
Full face respirator with filter, type P2L	0.2
Full face respirator with filter, type P3L	0.1
Half/full face powered air respirator TMP1 (particulate cartridge)	0.2
Half/full face powered air respirator TMP2 (particulate cartridge)	0.1
Half/full face powered air respirator TMP3 (particulate cartridge)	0.1
Full face powered air respirator TMP3 (particulate cartridge)	0.05
Hood or helmet with supplied air system TH1	0.2
Hood or helmet with supplied air system TH2	0.1
Hood or helmet with supplied air system TH3	0.05

As electret or electrostatic filters have shown to be less effective for reducing personal exposure to MNOs, compared to mechanical filters/ fibrous filter materials, the user should be informed when he/she uses such a filter.

2.5 Exposure bands

After the user has answered all the questions then the tool will calculate the Stoffenmanager score based on the scores for the individual parameters using the Stoffenmanager algorithm. The final exposure score will be assigned to an exposure band according to the following table:

Exposure band	**Range scores**
1	0 – 0.002
2	0.002 – 0.2
3	0.2 – 20
4	20 – 2000.03

2.6 Redirection to Stoffenmanager 4.0

After the user has prioritized the MNOs in his/her products, the user should be redirected to Stoffenmanager 4.0 to prioritize the other agents in the product.

3 Banding of hazard

Currently, due to the uncertainty related to their hazardous properties, all nanomaterials are considered as potentially (highly) toxic and should therefore be handled as such. The Dutch Social Economic Council (Sociaal Economische Raad, SER) recommends applying the precautionary principle (*i.e.* to avoid exposure when possible, or otherwise minimize exposure). Risk banding offers the possibility for the identification of potentially high concern MNOs and subsequent application of risk reduction measures, in cases where exposure to MNOs cannot be prevented.

3.1 Hazard banding in Stoffenmanager

The principle of hazard banding has been previously applied for exposure to non-nanomaterials in Stoffenmanager (Marquart *et al.*, 2008). Hazard banding for non-nanomaterials in Stoffenmanager is solely based on classification and labeling (C&L) as proposed by Directive 67/548 of the CLP Regulation. Five hazard classes have been distinguished in Stoffenmanager taking into account the presence or absence of a toxicological threshold, the severity of the effect and the potency of the substance (Brooke, 1998). The hazard banding as has been applied in Stoffenmanager is represented in the following table:

Hazard band	Target airborne concentration range	R-Phrases
A	> 1-10 mg/m^3 dust > 50-500 ppm vapour	R36, R38; all dusts and vapours not allocated to another band
B	> 0.1-1 mg/m^3 dust > 5-50 ppm vapour	R20/21/22, R40/20/21/22
C	> 0.01-0.1 mg/m^3 dust > 0.5-5 ppm vapour	R48/20/21/22, R23/24/25, R34, R35, R37, R39/23/24/25, R41, R43
D	<0.01 mg/m^3 dust <0.5 ppm vapour	R48/23/24/25, R26/27/28, R39/26/27/28, R40 Carc. Cat 3, R60, R61, R62, R63
E	Seek specialist advice	R40 Muta Cat 3; R42, R45, R46, R49
S: Skin and eye contact	Prevention or reduction of skin and/or eye exposure	R34, R35, R36, R38, R41, R43

Bands A-D have associated ranges of exposure by inhalation for dusts and vapours, which are intended to represent an adequate level of control for substances in the subsequent bands. Health effects raising most concern are assigned to hazard band E, whereas band S includes substances for which precaution is warranted to protect skin and eyes.

3.2 Hazard banding parameters for MNOs described in literature

Several hazard banding approaches for MNOs have been described in literature, although with different objectives. The categorisation of risk could be either related to human health effects associated with nanoparticle exposure at the workplace, potentially hazardous production processes or environmental/life-cycle considerations.

These subsequently vary both in complexity and in nature between highly conceptual and relatively pragmatic proposals. Importantly, hazard banding schemes can be distinghuished by the way decision criteria are implemented. In some approaches, the presence or absence of properties are directly related to the hazard category whereas others attribute an arbitrary score for each criteria, indirectly influencing categorisation.

A control banding tool of particular interest related to worker exposure is that described by Paik *et al.* (2009). In this strategy several hazard parameters are attributed a certain severity score, *e.g.* surface chemistry, particle diameter, and additional toxicity parameters of the parent material (such as dermal toxicity and occupational exposure limits (OEL)). Also, known hazards of the nanomaterial itself are taken into account and a sub-maximum severity score is attributed to parameters for which no information is available. The classification into one of four hazard categories is based on overall severity score taking into account the various parameters.

Overall, current hazard banding approaches are based on a limited number of parameters:

Structural/Physico-chemical

- Particle diameter and length
- Particle shape
- (water) solubility
- State of agglomeration
- Bioavailability and bioaccumulation
- (surface) reactivity/chemistry
- Critical functional groups
- Composition (*e.g.* purity, contamination)

Classification and labeling

- C&L for human health endpoints of bulk material
- C&L for human health endpoints for nanomaterial
- C&L for physico-chemical properties (*e.g.* flammability)
- C&L for additional substances used in the process

The suitability of these parameters for hazard banding in Stoffenmanager Nano is discussed in section 3.4.

3.3 Derivation of benchmark exposure levels for MNOs

The SER recommends to derive health-based occupational exposure levels for a number of commonly used MNOs (SER, 2009). However, The Dutch Health Council (Gezondheidsraad; GR) concluded that based on current knowledge, derivation of such values is not possible. Alternatively, the SER recommends the establishment of benchmark values for nanomaterials. These values should not be interpreted as health-based exposure values, as the derivation of these values does not have a scientific basis.

Nano benchmark values however do offer an indication for the level, duration and nature of exposure in practice for both employers and employees.

The British Standards Institution (BSI) has outlined a benchmark approach for exposure to nanomaterials (BSI, 2007). The "benchmark exposure levels" are based on a worst-case assumption that MNOs posses an increased toxicity when compared to bulk counterparts. These benchmark exposure levels are related to current worker exposure levels (WEL), but do not allow scientific justification. The 4 types of MNOs specified by BSI, including a proposal for the calculation of benchmark exposure levels (BSI, 2007) are presented in the following table:

Category	**Description category**	**Proposal for benchmark exposure level**
(1) Fibers	Insoluble fibers possessing a high aspect ratio (> 3:1) and a fiber length > 5000 nm).	10,000 fibers/m^3 (analogous to asbestos fibers, measured using SEM or TEM -scanning/ transmission electron microscopy)
(2) Carcinogenic/ Mutagenic/ Allergenic/ Reprotoxic	Nanomaterials of which the bulk form is classified for CMAR endpoints.	0.1 x WEL (Worker Exposure Limit) (mg/m^3) (safety margin of 10 to account for potential increased bioavailability of nanomaterial vs. bulk)
(3) Insoluble	Insoluble or low soluble nanomaterials not belonging to category (2)	0.066 x WEL (mg/m^3) (safety margin of 15 based on difference in exposure limit for fine (1,5 mg/m^3) and ultrafine (0,1 mg/ m^3) TiO_2 as proposed by NIOSH
		20,000 particles/cm^3 (to be discerned from background exposure) (based on current urban air pollution of 20,000 - 50,000 particles/ml)
(4) Soluble	Soluble nanomaterials not belonging to category (2)	0.5 x WEL (mg/m^3) (safety margin of only 2 since it is unlikely that soluble nanomaterials have a higher bioavailability compared to bulk form)

The German 'Institut für Arbeitsschutz der Deutsche Gesetzlichen Unfallversicherung' (IFA) has proposed an alternative concept to the BSI benchmark approach. Some important discrepancies compared to the BSI can be noted. When a dose is expressed as number concentration, the corresponding dose expressed on a mass basis is dependent on the mass density. Therefore, the IFA takes into account the mass density of MNOs for its proposed benchmark values. Second, the benchmark values proposed by the IFA are independent from the parent material. Overall, the IFA proposes a more generic approach currently resulting in 3 categories with a proposed benchmark value and 2 categories for which no benchmark value can or needs to be derived.

Category	Proposal for benchmark exposure level [a]
Metals, metal oxides and other biopersistent[b] granular MNO with a density > 6000 kg/m^3	20,000 particles/cm^3 in a range of 1 to 100 nm
Biopersistent granular MNO with a density < 6000 kg/m^3	40,000 particles/cm^3 in a range of 1 to 100 nm
Particles, agglomerates and aggregates > 100 nm	To be discussed (expressed as particles/cm^3 or mg/m^3?)
Carbon nanotubes which have not been tested for asbestos-like effects	10,000 fibers/m^3 (based on exposure-risk ratio of asbestos)
Nano-sized liquid particles (such as lipids, hydrogencarbons, siloxanes)	Current MAC or OEL

[a] 8-h TWA increase related to background levels

[b] Defined by IFA as'not biodegradable in the body'

The categorization and derivation of reference values as proposed by BSI and IFA have been reviewed previously (RIVM, 2010). In this context, the 'Deskundigenplatform Arbo', a panel of experts originating from KIR-nano, concluded that IFA proposal is an acceptable (simplified) alternative to the BSI approach. The IFA benchmark values can directly be applied, although for the category consisting of particles, aggregates and agglomerates no benchmark value has yet been proposed.

Although the establishment of benchmark exposure levels serves another purpose than the establishment of a control banding strategy, some principles can be shared such as the basis for categorisation of different types of MNOs. Since the implementation of the concept of benchmark values is supported by the Dutch Government, and in view of overall transparency, it would be desirable to match the hazard banding in the Stoffenmanager Nano tool with these reference values when possible. However, some aspects of deriving benchmark values for worker exposure differ fundamentally from the basis for establishing a control banding tool. For instance, the critical relationship between surface area, density and number concentration for exposure measurements is not necessarily relevant for attributing MNOs to a certain hazard band. Also, although information on biopersistence is of primary interest, this will not likely be available to users of the Stoffenmanager Nano. Therefore, solubility is a more usable parameter for hazard banding. Finally, the category of carbon nanotubes as defined by IFA does not take into account other high-ratio MNOs which theoretically, might possess similar toxicological properties due to their structure (Hamilton *et al.*, 2009).

3.4 Proposal for hazard categorisation

Initial considerations

Establishing a hazard banding framework for nanomaterials that corresponds with the approach used in the traditional Stoffenmanager makes it recognizable for the current Stoffenmanager. The use of R-phrases alone as has been applied in the generic Stoffenmanager however, is not sufficient for nanomaterials. In fact, other properties such as size and solubility are more likely to be of influence of hazard than parent material toxicity. The user is therefore asked to provide this additional data, and should be challenged to retrieve this data when not available.

For many parameters for which information is available, this information only relates to a single or few nanoparticles, making them not very suitable for a control banding tool. The most important criteria are 1) a clear relationship to the potential hazard of MNOs and 2) good availability and accessibility of the subsequent information. When in the nano-range, their size, physical form and surface chemistry of particles directly affect their hazard profile. However, the exact causal relationships between these parameters and hazard still need to be identified. For instance, regarding the presence of critical groups, insufficient information is available from which to derive certain hazard categories. Even for size, it is not yet very clear for what type of MNO its size is influencing its hazardous profile.

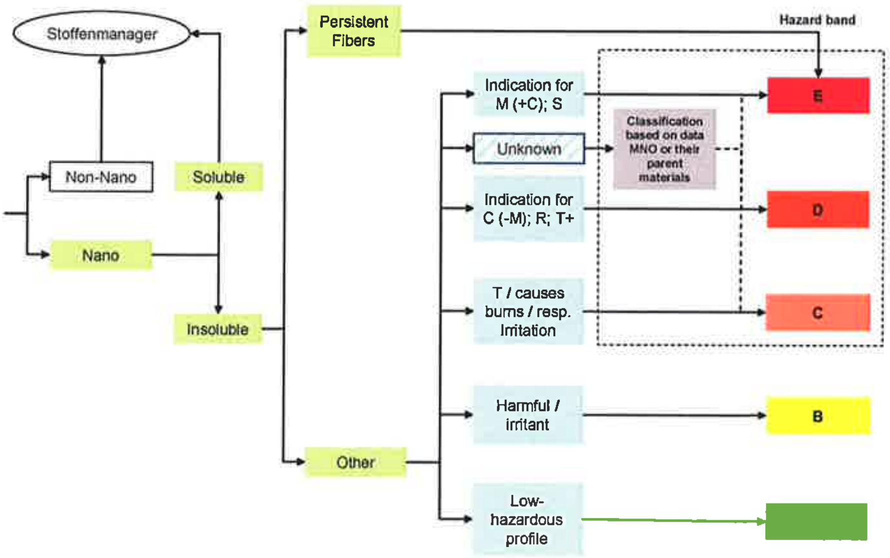
One can deal with these parameters in a (semi-)quantitative manner, by introducing 'weight factors' for each of the relevant parameters, as has been proposed by Paik *et al.* (2008). Otherwise, categories can be distinguished only on qualitative considerations. For the purpose of a hazard banding tool for SME, we find the latter approach more suitable in view of transparency (*i.e.* it provides direct justification for the attribution to a category rather than an arbitrary hazard score).

Our approach partly follows the considerations underlying the benchmark values proposed by BSI and IFA, by assigning nanofibers and soluble MNOs to specific classes. Furthermore, it shares similarity with the BSI approach as it takes into account the hazardous properties of the parent material (although applicable only for less commonly used MNOs).

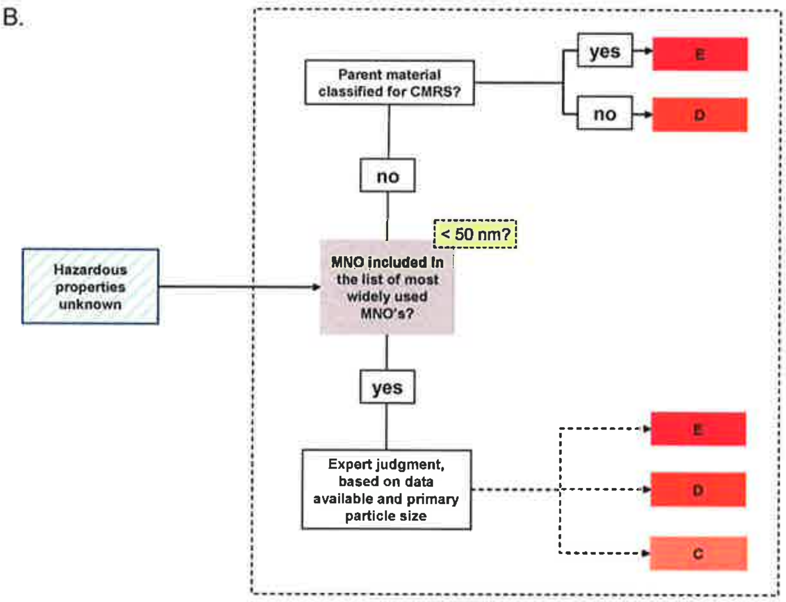
Hazard categories for the Stoffenmanager Nano tool.

The hazard bands in Stoffenmanager Nano are distinguished according to the following proposal:

A.



B.



Hazard banding framework:

(A) Overall hazard classification for the Stoffenmanager Nano-tool. It consists of 5 hazard classes for MNOs based on water solubility, structure (*i.e.* fiber-like or not), fiber length and hazard of the MNO itself.

(B) As the hazard of the MNOs is currently unknown, the hazard band is determined by expert judgment (for commonly used particles) or the classification of the parent material (other particles). For discussion see text.

Step 1: Primary size and/or surface area as exclusion criterion

The size of a particle determines whether the use of Stoffenmanager Nano is appropriate for this particle. Primary particles exceeding the MNO range (arbitrarily defined as a size range between 1-100 nm in at least one dimension) should therefore be excluded. It is important to note that agglomerates (independent of diameter) are considered as clusters of MNOs for which it is not unlikely that these agglomerates retain nanospecific properties or fall apart in individual MNOs.

For agglomates and aggregates, surface area gives a better indication for nanospecific properties than primary particle size. Therefore, Stoffenmanager Nano applies to those MNOs with a primary size between 1-100 nm and/or to products with a specific surface area of $\geq (1/\rho)$ 60 m^2/g (SCENIHR, 2010).

Step 2: Water solubility as surrogate parameter for biopersistence

Most concern has been raised for MNOs that are thought to be persistent in the body, most often at the site of exposure. Persistence is generally associated with a low water solubility (< 0.1 g/L), whereas MNOs that have a high water solubility/low log P_{ow} are generally considered as low-priority particles since nano-specific properties are expected to be lost when particles are in solution. Most MNOs however will be insoluble, and this is generally specified in the MSDS or product information sheet, therefore this criterium[5] is suitable as surrogate for persistence and gives an indication for the use of the generic Stoffenmanager vs Stoffenmanager Nano. In case water solubility is not known, the nanomaterial is considered non-soluble.

When particles are considered to be in the non-nano range (step 1) or soluble, the user should be redirected to the generic Stoffenmanager.

Step 3: Distinction of persistent nanofibers based on fiber length

One distinct group of MNOs is that comprising the nanofibers. Concern has been raised for asbestos-like carcinogenic effects after inhalation of fiber-shaped, insoluble MNOs. 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. Although the exact hazard for fiber-like MNOs has not yet been established, the severity of the potential health effect and the uncertainty relating the presence of a subsequent threshold warrants the classification of persistent nanofibers in the highest hazard category (E).

It might not always be possible for SME to identify fiber-like MNOs based on (product) information available (*i.e.* aspect ratio and/or particle length is not specified). MNOs are treated as nanofibers 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 at this stage as most MNOs don't belong to the group of fibers. As the absence of specific information for fibers will lead to misclassification, it should be emphasized to the user that information on size and shape is essential for an appropriate hazard classification.

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[5] The determination of water solubility and subsequent discrimination between 'soluble' and 'insoluble' presents difficulties both technically and for interpretation. Therefore, in case the water solubility of a particle is unknown or reported to be in a low range, it is considered as 'non-soluble'.

BSI proposed to define nanofibers as MNOs with an aspect ratio > 3:1 and a fiber length of 5,000 nm. In case the information available to the user indicates that a MNO involves a nanofiber, primarily its fiber length (*i.e.* > 5,000 nm) determines whether it is treated as a persistent fiber in Stoffenmanager Nano (it is assumed that its diameter is the nano-range). Due to this relatively broad definition it is not unlikely that certain nano-fibers (such as flexible carbon nanotubes) which 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 experts. Therefore, handling all >5,000 nm nanofibers as persistent fibers is considered appropriate from a precautionary point of view.

Step 4a: Categorisation based on hazard indication of MNO itself

For MNOs other than persistent fibers, the hazard indication of the MNO itself should be considered. Although in most cases this information is lacking, a theoretical categorisation ranging from A (practically non-hazardous) to E (non-threshold effects such as sensitisation) can be imagined for future use when more nano-specific information on hazard is available.

Considering the situation in which comprehensive hazard data are available, MNOs associated with carcinogenicity and mutagenicity/sensitisation (often considered as effects for which no practicle threshold can be derived) are assigned to category E. MNOs with pronounced toxicological profiles (equivalent to T (toxic) or T+ (very toxic) or associated reprotoxic properties are placed in the second highest hazard band D. This categorisation rougly follows that applied for bulk chemicals in the generic Stoffenmanager.

Currently, hazard of most if not all fall MNOs are (at least partly) unknown. For the most widely used MNOs, the hazard category is based on the limited information available on the MNO and the hazardous properties of the parent material. Currently, in absence of specific information, the hazardous properties of the parent material provide a basis for hazard categorisation of nanoparticles. However, it should be stressed that it is not yet known to which degree the toxicity of nanoparticles is influenced by the hazard of their parent materials.

For the most widely used MNOs, the following categorisation is proposed by TNO based either on nano-specific data or their parent materials:

Type of NMO	*Hazard band*	*Based on*
C60 (fulleres)	D	Particle specific data
Carbon Black	>50 nm: C ≤ 50 nm: D	Parent material and (limited) particle specific data
Ag (nano Silver)	>50 nm: C ≤ 50 nm: D	Parent material and (limited) particle specific data
Fe (Iron)	>50 nm: C ≤ 50 nm: D	Parent material and (limited) particle specific data
Au (Gold)	>50 nm: C ≤ 50 nm: D	Parent material and (limited) particle specific data
Pb (Lead)	E	EPA Carc. B2; probable human carcinogen
La (Lanthanide)	>50 nm: C ≤ 50 nm: D	Parent material and (limited) particle specific data
TiN (Titanium nitride)	>50 nm: C	Parent material and (limited)

	≤ 50 nm: D	particle specific data
TiO_2 (Titanium dioxide)	>50 nm: C ≤ 50 nm: D	Parent material and (limited) particle specific data
CeO_2 (Cerium oxide)	>50 nm: C ≤ 50 nm: D	Parent material and (limited) particle specific data
ZnO (Zinc oxide)	>50 nm: C ≤ 50 nm: D	Parent material and (limited) particle specific data
SiO_2 (Sillica or silicon dioxide)	Unknown: E Crystalline /quartz: E Amorph, < 50 nm: D Amorph, > 50 nm: C	Particle specific data[6]
Al_2O_3 (Aluminium oxide)	>50 nm: C ≤ 50 nm: D	Parent material and (limited) particle specific data
FeO (Iron oxides)	>50 nm: C ≤ 50 nm: D	Parent material and (limited) particle specific data
Sb_2O_5 (Antimony oxide or Antimony pentoxide)	E	Parent material classified as Carc Cat 3; R40
SnO_2 (Tin oxide)	>50 nm: C ≤ 50 nm: D	Parent material and (limited) particle specific data
CoO (Cobalt oxide)	E	Parent material labeled R43
Nanoclay	>50 nm: C, ≤ 50 nm: D	Parent material and (limited) particle specific data
Polymers	>50 nm: C ≤ 50 nm: D	Parent material and (limited) particle specific data
nano-polystyrene	>50 nm: C ≤ 50 nm: D	Parent material and (limited) particle specific data
Dendrimers	>50 nm: C ≤ 50 nm: D	Parent material and (limited) particle specific data
Other MNOs[7]	Parent material unknown: E Parent material classified for C, M, R or S: E Not classified for C, M, R or S: D	

It should be stressed that the proposed hazard bands are based on limited data and not thoroughly substantiated. In a later stage, more data will be available (*e.g.* from the OECD Sponsorship program) for a more scientifically justified analysis.

Most of the parent materials commonly used have not been classified. In the generic Stoffenmanager, these substances would normally be assigned to hazard band A. From a precautionary principle, nanoparticles derived from these parent materials are assigned to hazard band C when the primary particle size is > 50 nm. Nanoparticles derived from non-classified parent materials which are ≤ 50 nm are assigned to hazard band D. This additional –arbitrary - size criterium has been introduced to take into account the likelyhood of the occurrence of nano-specific effects e.g. increased reactivity. It has been generally accepted that this likelyhood increases with a reduction in size, whereas MNOs approaching the non-nano size range are more comparable with their bulk counterparts. It remains to be determined whether this assumptions holds true for most MNOs, however at this moment it appears rational to introduce an arbitrary cut-off value to be able to discriminate between MNOs in the lower nano-range and

[6] Crystalline silica/quartz has been associated with carcinogenicity (IARC)
[7] MNOs containing several parent materials: most critical hazard band

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).

For certain MNOs associated with specific hazardous properties, or containing parent material with severe hazard, higher hazard bands are proposed.

Lead and Antimony (tri)oxide are suspected carcinogens (but not mutagenic and therefore their potential carcinogenicity is expected to occur only at exposure above a certain threshold). For MNOs containing one of these parent materials, hazard band E is proposed from a precautionary point of view. Crystalline Silica/quartz has been shown to be much more toxic than the amorph form. Crystalline Silica/quartz is therefore assigned to hazard band E. Cobalt is labeled R42/43 (May cause sensitization by inhalation and skin contact). As R42 would lead to category E in the generic Stoffenmanager, this classification in Stoffenmanager Nano is also warranted for MNOs containing cobalt independent of their size.

Step 4b: Categorisation based on parent material

MNOs other than specified in the table are ranked according to their parent material. These are assigned to hazard band E when their parent material is classified for either carcinogenicity, mutagenicity, reproduction toxicity or sensitisation (R40, R42, R43, R45, R46, R49, R68). In all other cases, hazard band D is applied. If the parent material is unknown, hazard band E is assigned for precautionary purposes (hazard figure B).

Importantly, in view of lack of specific data and according to precautionary principles these particles are attributed to relatively high hazard categories compared to the generic Stoffenmanager.

4 Banding of risk

4.1 Risk banding for MNOs described in literature

A limited number of articles are available regarding risk banding of MNOs. The most important publications regarding risk banding of MNOs are discussed in appendix 2.

The four control bands, *i.e.* ‘general ventilation’, ‘engineering control’, ‘containment’ and ‘seek specialist advice’, as defined by Maynard (2006) and adopted by Paik *et al.* (2008) are in line with the control bands used in the implementation of control banding through COSHH Essentials program described by the HSE (1999). The use of these control bands is evaluated by Zalk *et al.* (2009). A high level of consistency has been found when comparing the CB Nanotool risk level outcomes to expert industrial hygienists’ recommendations. There seems to be a tendency for the CB Nanotool’s qualitative risk assessment approach to err toward the conservative at times; however, industrial hygiene experts also agree that it is better to err toward over-control rather than under-control.

Within Stoffenmanager (Marquart *et al.* 2008) priority bands in stead of control bands are used. Stoffenmanager enables the user to design a risk reduction scenario or control scenario, by guiding the user towards control measures that are expected to ensure the best control measure. These control measures include the measures general ventilation, engineering control and containment as described by Maynard (2006), Paik *et al.* (2008) and HSE (1999). Subsequently the user is able to estimate the exposure based on the use of the control measure that could be implemented. The possibility of testing the possible effect of the implementation of a certain control measure on the risk priority is an advantage with respect to models lacking this possibility. Although, the effectiveness of control measures is not fully know regarding exposure to MNO. At this moment the assumption is made that localized controls (segregation, separation, ventilation etc.) and personal protective equipment are equally effective for conventional substances and MNO.

In parallel with Stoffenmanager, we propose a relative risk banding for Stoffenmanager Nano. The use of control bands as proposed by other control banding tools seems less relevant because it is possible to include control measures in the algorithm of the exposure banding (by the parameters: localized controls, personal enclosure, dilution and PPE). Stoffenmanager Nano should enable users to design a risk reduction scenario or control scenario likewise as included in the existing Stoffenmanager by guiding the user towards control measures that are expected to ensure the best reduction. The SAP (SAP, 2010) agrees with this approach.

4.2 Risk banding scheme for Stoffenmanager Nano

The results from the exposure and hazard banding steps are combined in the Stoffenmanager Nano into risk bands. These risk bands provide a relative ranking of risks for activities for individual workers. No quantitative comparison between exposure levels and hazard levels can be made because both exposure and hazards bands are based on qualitative considerations. The result of the risk banding should therefore be considered as a ‘priority band’. It was decided to make three priority bands because fewer bands would lead to an over-simplified representation of risk, while more bands would suggest more precision than warranted. The combination of hazard (5 bands) and exposure (4 bands) into priority or risk bands for the Stoffenmanager Nano is presented in the figure below.

Exposure band \ Hazard band	A	B	C	D	E
1	3	3	3	2	1
2	3	3	2	2	1
3	3	2	2	1	1
4	2	1	1	1	1

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.

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 similar to that of the generic Stoffenmanager. The classification of situations into priority- or risk bands is based on the 5 bands of hazard and 4 bands of exposure. Allocation into risk bands was done in such a way that exposure to very high hazard 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 associated with a high risk band 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 leads to high priority band for all hazard categories except category A. It should be emphasized that currently, in view of general lack of information, no MNO will be assigned to hazard band A or B. The subsequent allocation has been done to ensure a generally increasing risk band with increasing concern for exposure and/or hazard. Final allocations are, of course, partly arbitrary.

The SAP (SAP, 2010) agrees with the proposal.

5 Discussion / future

In the present document we described the development of a qualitative 'control banding' tool (Stoffenmanager Nano) for prioritizing the risk caused by exposure to MNOs. For a CB tool, like Stoffenmanager Nano, intended to be used by small and medium-sized enterprises (SME), operational quality is of major importance since specific expertise in chemical risk assessment and risk management is often lacking. Subsequently, information needed to use such a tool should be accessible and understandable for the user. Presently, as discussed in this document, lots of information for important parameters of exposure to MNOs is missing or not easily accessible and understandable. For example, information regarding dustiness is not available yet for almost all MNOs. Consequently, in this first version of Stoffenmanager Nano some assumptions and simplifications had to be made. As the precautionary principle is kept in mind and the model is supposed to result in a rough prioritisation, the assumptions and simplification made are acceptable.

In future versions of Stoffenmanager Nano some parameters of exposure should be explored and included in more detail when new information becomes available. These parameters of concern are:

- Far field exposure - Simplified with respect to the conceptual model described by Schneider *et al.* (2011);
- Coagulation and scavenging – Not included due to the complex influence of this parameter. It is too difficult to include this parameter in an easy-to-use model at this moment;
- Dustiness - For nano powders the key parameter for substance emissions is dustiness (Schneider *et al.*, 2011). Unfortunately, for most, if not all, nanopowders the quantitative dustiness is not known at present. In addition, physico-chemical properties or other characteristics as indicated in Product Information Sheets that could be indicators/ determinants for dustiness are not studied in detail to relate these to substance emission potential.
  Until dustiness of MNOs can be included in a quantitative way the highest dustiness class is given as default. If the exact dustiness of the powder is known, then the user is able to select a lower dustiness category when applicable;
- Characteristics of the mixtures for MNOs dispersed in a liquid - The effect of type of liquid, vapour pressure, surface tension of the mixture on exposure to particles is unknown, but probably has a great influence on exposure. Therefore, some product characteristics should lead to a high substance emission score. However, more information is needed to include scoring for these characteristics in the substance emission potential.
  One exception is made to include substance emission. Within Stoffenmanager Nano for the scenario spraying Nanofilm a high handling score is defined to include the substance emission in an alternative manner. During this scenario particles are released using a high volatile mixture resulting in a layer of individual nanoparticles. Due to the use of a high volatile mixture and the high pressure it seems likely that individual particles will go into the air due to evaporation of the mixture. In the future more information should be obtained to include these parameters in a more appropriate manner;
- Activity emission potential - The source domain 'release of primary particles during synthesis' involves (new) production processes. During the processes particles will be released unintentionally from the ractor, connections, valves etc. In addition

during most of the processes heat is used which also results in production of nanoparticles that are not of interest. It is difficult to define Stoffenmanager scores for these processes as the task performed mostly concerns controlling the system;
- Localized control - A broad range of control measures is available (Fransman *et al.* 2009). Not all control measures are included in this first version of Stoffenmanager Nano. In the future addition of other control measures should be explored.
- Separation - It was decided not to add categories for partial separation as described by Fransman *et al.* (2009) due to the large variability of the effectiveness of partial separation. In the future versions of Stoffenmanager Nano this parameter might be added if more information is available.
- Ventilation - Experts in the field of ventilation from TNO Built Environment and Geosciences defined some additional parameters important for ventilation. Information regarding the capacity of available ventilation types and more information about the room e.g. openings in the roof and/or outer walls could be included. In the future including these parameters should be explored in more detail.

In addition to the parameters of exposure discussed above, some remarks regarding hazard should be explored and possibly adapted in the future. These remarks of concern are:
- It might not always be possible for SME to identify fiber-like MNOs based on (product) information available (*i.e.* when aspect ratio and/or particle length is not specified). Since most MNOs are not nanofibers, MNOs are only treated as nanofibers when there is *an indication for fiber-like properties* (either in size range or nomenclature). As the absence of specific information on fibers will lead to misclassification, it should be emphasized to the user that information on size and shape is essential for an appropriate hazard classification.
- Currently, insoluble nanofibers are assigned to hazard category E. This generalisation of hazardous properties has been debated. Currently, the information available does not allow the user of Stoffenmanager Nano to conclude on the potential persistence of nanofibers. Therefore, this worst-case approach for fibers is considered appropriate at this moment.
- To take into account differences in size (*e.g.* MNOs of 5 nm versus 90 nm but derived from the same parent material) a cutt-off value is proposed of 50 nm. It is emphasized that criterion is defined as an arbitrary value between 1 and 100 nm, which should be refined when specific data are available.
- For a list of the most widely used MNOs a categorisation is proposed based on properties of either the nano-form or their parent material. This list is based on limited data and not thoroughly substantiated. When more information becomes available this list should be adjusted where appropriate.
- When MNOs cannot be categorised based on a hazard indication of the MNO itself, MNOs are categorised based on parent material. In view of lack of specific data and according to precautionary principles, these particles are attributed to relatively high hazard categories compared to proposed hazard bands for these parent materials in the generic Stoffenmanager.

6 Literature

BECO. Eindrapportage generieke Stoffenmanager 4.0. Arbo verplichtingsnummer 5140-2649, December 2008.

Bello D, Wardle BL, Yamamoto N, deVilloria RG, Garcia EJ, Hart AJ, Ahn K, Ellenbecker MJ, Hallock M. Exposure to nanoscale particles and fibers during maching of hybrid advanced composites containing carbon nanotubes. J. Nanopart Res. 2009: 11:231-249.

Brooke IM. A UK scheme to help small firms control health risks from chemicals: toxicological considerations. Ann Occup Hyg. 1998; 42(6):377-90.

Brouwer D. Exposure to manufactured nanoparticles in different workplaces. Toxicol 2009 Doi:10.1016/j.tox.2009.11.017

Brouwer DH, Aitken RJ, Oppl R, Cherrie JW. Concepts of skin protection: Considerations for the evaluation and terminology of the performance of skin protective equipment. J Occup Environ Hyg 2005: 2:425-34.

BSI. Nanotechnologies - Part 2: Guide to safe handling and disposal of manufactured nanomaterials, PD 6699-2-2007, Londen : British Standards Institution. Available from: http://www.bsigroup.com/en/sectorsandservices/Forms/PD-6699-2/Download-PD6699-2-2007/ [gedownload op 4 september 2009].

Cherrie JW, Schneider T, Spankie S et al. New method for structured, subjective assessement of past concentrations. Occup Hyg. 1996; 3: 75-83.

Cherrie JW, Schneider T. Validation of a new method for structured subjective assessment of past concentrations. Ann. Occup Hyg 1999; 43: 235-245

Fransman W, Schinkel J, Meijster T, van Hemmen J, Tielemans T, Goede H. Development and Evaluation of an Exposure Control Efficacy Library (ECEL). Ann Occup Hyg. 2008; 52(7):567-575

Fransman W, Cherrie J, van Tongeren M, Schneider T, Tischer M, Schinkel J, Marquart H, Warren N, Kromhout H, Tielemans E. Development of a mechanistic model for the Advanced REACH Tool (ART). TNO report V8667. 2009

Genaidy A, Sequeira R, Rinder M, A-Rehim A. Risk analysis and protection measures in a carbon nanofiber manufacturing enterprise: an exploratory investigation. Sci Total Environ. 2009; 407(22):5825-38

Hamilton RF, Wu N, Porter D, Buford M, Wolfarth M, Holian A. Particle length-dependent titanium dioxide nanomaterials toxicity and bioactivity. Part Fibre Toxicol. 2009; 31: 6-35.

Höck J., Hofmann H., Krug H., Lorenz C., Limbach L., Nowack B., Riediker M., Schirmer K., Som C., Stark W., Studer C., von Götz N., Wengert S., Wick P.:

Precautionary Matrix for Synthetic Nanomaterials. Federal Office for Public Health and Federal Office for the Environment, Berne 2008.

HSE. http://www.coshh-essentials.org.uk/. 1999

International Organization for Standardization Nanotechnologies -- Terminology and definitions for nano-objects -- Nanoparticle, nanofibre and nanoplate. ISO TS 27687 Geneva, Switserland, 2008(b).

Koponen IS, Jensen KA, Schneider T. Comparison of dust released form sanding conventional and nanoparticle-doped wall and wood coatings. Journal of exposure science and environmental epidemiology. 2010; 1-11

Luther W. Industrial applications of manufactured nanomaterials-chances and risks. Future Technol No. 54, VDI Technologiezentrum GmbH, Dusseldorf, Germany, 2004.

Ma-Hock L, Gamer A.O., Landsiedel R., Leibold E., Frechen T., Sens B., Linsenbuehler., van Ravenzwaay B. Generation and characterization of test atmospheres with nanomaterials. Inhal Toxicol 2007; 19: 833-848

Marquart H, Heussen H, Le Feber M, Noy D, Tielemans E, Schinkel J, West J, Van der Schaaf D. 'Stoffenmanager', a web-based control banding tool using an exposure process model. Ann. Occup. Hyg. 2008; 52(6): 429-441

Maynard AD. Nanotechnology: The next best thing, or much about nothing? Ann. Occup. Hyg. 2006: 1-12

Money CD. European experiences in the development of approaches for the successful control of workplace health risks. Ann Occup Hyg 2003; 47:7; 533-540.

NIOSH. Evaluation of Health Hazard and Recommendations for Occupational Exposure to Titanium Dioxide: NIOSH Current Intelligence Bulletin: Draft document for public review and comment, Cincinnatti, OH : National Institute for Occupational Safety and Health, 22 november 2005. Available at: http://www.cdc.gov/niosh/review/public/TIo2/pdfs/TIO2Draft.pdf [visited 3 november 2009]

NIOSH. Qualitative risk characterization and management of occupational hazards: control banding (CB). Publication No. 2009–152. 2009 Available at: http://www.cdc.gov/niosh/docs/2009-152/. [visited May 19, 2010]

Paik SY, Zalk DM, Swuste P. Application of a pilot control banding tool for risk level assessment and control of nanoparticle exposures. Ann Occup Hyg. 2008; 52(6):419-28

Rijksinstituut voor Volksgezondheid en Milieu (RIVM), Tijdelijke nano-referentiewaarden Bruikbaarheid van het concept en van de gepubliceerde methoden. RIVM Rapport 601044001/2010.

Robichaud CO, Tanzil D, Weilenmann U, Wiesner MR. Relative risk analysis of several manufactured nanomaterials: an insurance industry context. Environ Sci Technol. 2005; 39(22): 8985-94

SCENIHR. Scientific Basis for the Definition of the Term "Nanomaterial". Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), July 6, 2010.

Science advisory panel (SAP). A teleconference was organized by the Stoffenmanager consortium to discuss the proposal for Stoffenmanager Nano. Participitants were: Keld Alstrup Jensen (NCWE), David Zalk (NLFL), Martie van Tongeren (IOM), Daniel Bloch (ISO TC229 and CEA France), Cees de Heer (RIVM), Christine Northage (HSE), Henri Heussen (Arbo Unie), Petra Beurskens (Arbo Unie), Koen Verbist (Arbo Unie), Stefan Vink (TNO), Birgit van Duuren-Stuurman (TNO), Dick Brouwer (TNO), Maikel van Niftrik (TNO, minutes) and Erik Tielemans (TNO, chair)
Minutes are available. April 22, 2010.

Schinkel J, Fransman W, Heussen H, Kromhout H, Marquart H, and Tielemans E. Cross-validation and refinement of the Stoffenmanager as a first tier exposure assessment tool for REACH. Occup Environ Med. 2010. 67(2):125-32.

Schneider T, Brouwer DH, Koponen IK, Jensen KA, Fransman W, van Duuren-Stuurman B, Van Tongeren M, Tieleman E. Conceptual model for assessment of inhalation exposure to manufactured nanoparticles. J. Expo. Sci. Environ. Epidemiol. Accepted for publication (2011)

Schneider T and Jensen K. A. Relevance of aerosol dynamics and dustiness for personal exposure to manufactured nanoparticles. J. Nanopart Res. 2009;11:1637-1650

Schulte P, Geraci C, Zumwalde R, Hoover M, Kuempel E. Occupational risk management of engineered nanoparticles. J Occup Environ Hyg. 2008; 5(4):239-49

SER 'Veilig omgaan met nanodeeltjes op de werkplek'. Advies van de Commissie Arbeidsomstandigheden. Den Haag: Sociaal Economische Raad. Avialable at: http://www.ser.nl/~/media/DB_Adviezen/2000_2009/2009/b27741.ashx [visited 3 november 2009].

Seipenbusch M, Binder A, Kasper G. Temporal evolution of nanoparticle aerosols in workplace exposure. Ann. Occup. Hyg. 2008; 52: 707-716

Tervonen T, Linkov I, Rui Figueira JR, Steevens J, Chappell M, Merad M. Risk-based classification system of nanomaterials. J Nanopart Res (2008).

Tielemans E, Noy D, Schinkel J, Heussen H, Van der Schaaf D, West J, Fransman W. Stoffenmanager exposure model: development of a quantitative algorithm. Ann. Occup. Hyg. 2008a; 1-12

Tielemans E., Schneider T., Goede H., Tischer M., Warren N., Kromhout H. *et al.* Conceptual Model for Assessment of Inhalation Exposure: Defining Modifying Factors. Ann.Occup Hyg 2008b: 52: 577-586.

Vorbau M, Hillemann L, Stintz M. Method for the characterization of the abrasion induced nanoparticles release into air from surface coatings. Aerosol Science 2009; 40:209-217

Wardak A, Gorman M, Swami N, Deshpande S. Identification of Risks in the Life Cycle of Nanotechnology-Based Products. Journal of Industrial Ecology. 2008; 12(3): 435-448

Zalk DM, Paik SY, Swuste P. Evaluating the Control Banding Nanotool: a qualitative risk assessment method for controlling nanoparticle exposures. J Nanopart Res 2009; 11: 1685-1704

7 Signatures

Zeist, 02-02-2011

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Literature on exposure banding

.1 Control banding of exposure

A limited number of publications are available regarding exposure banding. The most important publications regarding exposure banding of nanoparticles are discussed below. The parameters included for exposure banding are described below and compared with the exposure banding as used within Stoffenmanager.

Genaidy *et al.* (2009) have described a qualitative risk analysis applied to carbon nanofiber plant. Within this approach the level of probability of exposure is banded in 5 bands:

- improbable (probability of occurrence cannot be distinguished from zero (less than 0.0001%))
- remote (not likely to occur in system life cycle, but possible (between 0.0001% – 0.1%)
- occasional (likely to occur sometime in system life cycle (between 0.1 % - 1%)
- probable (likely to occur several times in system life cycle (between 1% - 10%)
- frequent (likely to occur repeatedly in system life cycle (>10%)).

Only carbon fibers are addressed in this survey. The categorization used in this model is quite robust using only the parameter 'occurrence' to describe exposure. The parameter 'occurrence' is not addressed in Stoffenmanager.

Wardak *et al.* (2008) have described exposure bands within a control banding approach based on the probability of scenarios and so-called 'risk-triggers' regarding exposure. The scenarios are described as: inhalation, skin absorption, ingestion, water entrainment or air release. The exposure-related risk triggers are defined as:

- New product. A new product can potentially be more risky than an existing product because of unknown exposure scenarios or the amount of nanomaterial in the product might be used. Unknown exposure scenarios or higher amounts used increases the likelihood of exposure.
- Coating stability. Are there know scenarios where the coating breaks down? Break down might increase the likelihood of nanotechnology-related risks.
- Media-dependent properties. Do the nanomaterials in the nano-product behave or act significantly different in different media (air, soil, water)? If the nano-product changes significantly in different media outside its intended application, then the exposure likelihood increases.
- Used in conjunction with other products. Synergistic effects that arise due to interaction of one product component with another might give rise to a higher risk. Is the nano-product used in conjunction with other products that may raise such exposure pathways?
- Multiple disposal pathways. Is the product disposal pathway (e.g. recycling, trash) fixed? Multiple pathways to disposal create more risk scenarios and further consideration.
- Particle size under 200 nm. Is the nanomaterial present in the nano-product under 200 nm in size? At sizes below 200 nm, surface phenomena dominate the exposure pathways due to high surface-to-volume ratios.

- Dispersibility and bioavailability. Does material become dispersed as free nanoparticles, or is there a coating that makes it less dispersible? If it is dispersed as a free nanoparticles, this increases its bioavailability.
- High aspect ratio. Does the aspect ratio cause the material to be more easily transported in the environment? Fiberlike structures may increase their environmental mobility.

For each scenario and risk trigger the probability is defined within five categories: high, medium-high, medium, medium-low and low. These five categories are converted to scores from 5 for the category high to 1 for the category low. To come to an exposure band the average of scores of the risk-triggers should be taken for each scenario. The CB approach is tested by proof-of-concept. Experts were asked to score exposure for a case-study. The scoring for the different scenarios and exposure-related risk triggers was very subjective as no clear descriptions of the categories is given, which might result in misclassification.

Most risk-triggers described above are not included in Stoffenmanager. Part of the risk-trigger 'new product' (e.i. amount handled) however, is included in Stoffenmanager. In addition 'dispersibility and bioavailability' is probably included in Stoffenmanager as dustiness. 'Used in conjunction with other products' might be included in Stoffenmanager within the parameter 'substance emission potential'. The other risk-triggers are not included in Stoffenmanager.

Maynard (2006) has proposed a conceptual control banding approach in which an exposure index could be based on the amount used and dustiness of the studied nanoparticles. In his manuscript Maynard states that the model is still very much at a conceptual stage and would require much more development to make it workable. Zalk *et al.* (2008,2009) has used the conceptual control banding model described by Maynard (2006) to develop a pilot control banding nanotool. The applicability domain was limited to research and development laboratories. Within this model they based the probability (exposure) factor of the risk matrix on the following parameters:

- Amount used. For nanomaterials embedded on substrates or suspended in liquid, the amount is based on the nanomaterial compound itself and not the substrate or liquid portion. Four categories are defined: > 100 mg, 11-100 mg, 0-10 mg and unknown (when the amount handled is not known).
- Dustiness/mistiness. Five categories are defined: High, medium, low, unknown (when the dustiness/mistiness is not known) and none. 'None' should for example be chosen by the handling of nanoparticles embedded on fixed substrates and working with non-agitated liquid suspensions. When the user chooses 'none', then the overall probability score automatically will be 'extremely unlikely'.
- Number of employees performing similar operations. Points are assigned by the number of employees assigned to the activity. More employees means a higher probability an employee being exposed. Five categories are defined: > 15, 11-15, 6-10, 1-5 and unknown (when the number of employees is not known).
- Frequency of operation. More frequent operations are more likely to result in employee exposures. Five categories are defined: daily, weekly, monthly, less than monthly and unknown (when the frequency is not known).
- Duration of operation. Prolonged operations are more likely to result in employee exposures. Five categories are defined: > 4 h, 1-4 h, 30-60 min, < 30 min, unknown (when the duration is not known).

Addition of information regarding the opportunity of exposure (number of employees performing similar operation, frequency of operation, duration of operation) will give a more detailed assessment of the probability of exposure than only including amount used and dustiness/mistiness. The user has to a give a score to all the different probability factors. The scores are given based on limited number, 4 or 5, of categories that are described above in detail. The model is therefore easy to use. The sum of the scores leads to one of the four exposure bands. Within the model it is possible to attribute a score to a parameter even when the information is not available. In these cases the user chooses the category 'unknown' for a parameter. In these cases the score is 75% of the highest score for the parameter.

Within Stoffenmanager the parameters 'amount used' and 'dustiness' are included in the model, although more categories are defined for both parameters and 'amount handled' is taken into account by the description of activity. 'Number of employees' is not directly addressed in Stoffenmanager; when one or more other employees are working in the same room as the activity for which the assessment is performed a far-field source is included.

The Federal Office of Public Health (FOPH) and Federal Office of the Environment (FOEN) have proposed a precautionary matrix for synthetic nanomaterials (Höck *et al.*, 2008). Within this matrix level of exposure of humans is based on:

- Physical surroundings of the nanoparticles. Categories are defined for nanoparticles in liquid media (as aerosols < 3 µm, as exposure via mouth, throat, stomach and intestine (>3 µm), by skin), in solid matrix (not stable under conditions of use, stable under conditions of use (nanoparticles mobile), stable under conditions of use (nanoparticles not mobile)) or the physical surrounding is air. When the particles are embedded in media or a solid matrix then the likelihood of exposure is lowered.
- Possible amount resulting in contact. The possible amount with which a worker comes into contact per day is defined for 'normal' workdays and in 'worst case'. For 'normal' the categories are defined as: < 25 µg, < 250 µg , > 250 µg. For the 'worst case' situation the categories are defined as: < 250 µg , < 2500 µg, > 2500 µg. The higher the possible amount resulting in contact the higher the score.
- Frequency of handling of nanoparticles. The categories which are defined are: 'monthly', 'weekly', 'daily'. The higher the frequency of handling, the higher the score.

The level of exposure is multiplied with a potential effect and a factor for nano-relevance to come to a single score. No specific exposure bands are defined, which makes the model not directly applicable. The parameter 'physical surrounding' is not directly considered in Stoffenmanager. Within Stoffenmanager, the dustiness and volatility give an indication of availability of nanoparticles. The parameters 'amount used' and 'frequency' are also included in Stoffenmanager.

Most of the parameters included in the CB approaches described above are covered directly or indirectly (included within another parameter, for example amount handled which is included in the activity emission potential) within Stoffenmanager.

In summary, the following parameters in addition to those included in Stoffenmanager are proposed in literature regarding control banding of MNO:

- New product (Wardak *et al.*, 2008)
- Disposal pathways (Wardak *et al.*, 2008)
- Stability of coating (Wardak *et al.*, 2008)
- Media-dependent properties (Wardak *et al.*, 2008)
- Particle size < 200 nm (Wardak *et al.*, 2008)
- High aspect ratio (Wardak *et al.*, 2008)
- Used in conjunction with other products (Wardak *et al.*, 2008)
- Number of employees (Zalk *et al.*, 2008, 2009)

.2 Conceptual model for exposure assessment of nanoparticles

Schneider *et al.* (2011) have developed a conceptual model for assessment of inhalation exposure to MNO, to provide a framework for future exposure models. Basically, the conceptual nano model consists of the same structure as the conceptual model for inhalation exposure that is used within the Advanced REACH Tool (ART) (Tielemans *et al.*, 2008b; Fransman *et al.* 2009). The conceptual model is constructed using three components, *i.e.* the source, various transmission compartments and the receptor, and describes the contaminant's emission and its pattern of transport.

The source represents an activity during which a substance is emitted into the air. The source is described by the parameters 'substance emission potential' and 'activity emission potential'.
The transmission compartments that are distinguished are:

1) a 'local control influence region' (LCIR) which is a virtual boundary around a source and represents the zone of influence for localized control.
2) The near-field and far field compartments. The near-field (NF) compartment is conceptualized as a volume of air within 1 m in any direction of the worker's head. The far field (FF) comprises the remainder of the room. Hence, the concept of NF–FF can be considered as a box-inside-of-a-box, where the worker moves around in the FF zone with an enveloping NF zone.
3) Compartments defined by enclosures, such as source enclosure (segregation) and personal enclosure (separation).
4) Surface contamination (e.g. workbench, wall, but also personal clothing) that by the chemical of interest through general deposition in the work environment or adsorption constitute the surface compartment or several distinct compartments if needed.

The third component is the receptor. This component represents the respiratory tract of the worker which can be influenced by the use of personal protective equipment.

The modifying factors describing exposure within the conceptual model are described below:

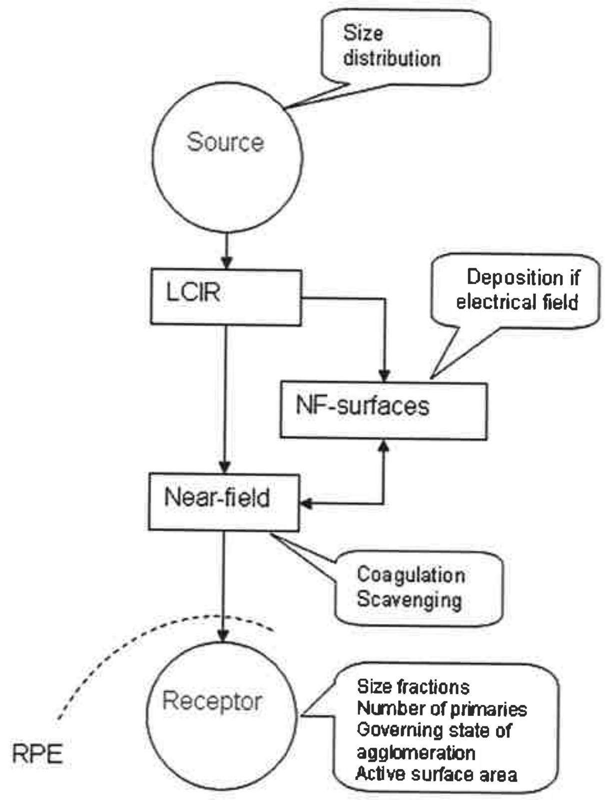
- Source. The source of exposure can be described as the substance emission potential and activity emission potential. For a solid, the emission potential is based on its dustiness. For liquids, information on volatility and concentration is needed. The activity emission potential is determined by level of energy, scale (amount of product used), and product-to-air interface, *i.e.* level of containment, during a particular activity. The assumption is made that the following source domains include the vast majority of current and near-future exposure situations for manufactured nano objects:

  - release of primary particles during synthesis (*e.g.* sampling, maintenance, cleaning);
  - handling of bulk aggregated/ agglomerated nanoparticles in products (*e.g.* bagging, dumping, handling contaminated bags);
  - spraying or dispersion of a ready-to-use nanoproduct (*e.g.* spray application with aerosol formation);
  - fracturing and abrasion of nanoparticles-embedded end products (*e.g.* machining - sanding, milling, cutting)
- Coagulation and scavenging. Nanoparticles emitted prior to harvesting may coagulate rapidly during the transport to the receptor and manufactured nanopowders have a tendency to agglomerate. Consequently, a conceptual nano-model must take into account:
  - Coagulation of nanoparticles emitted from a production line or reactor prior to harvesting by both homogeneous coagulation between manufactured nanoparticles and scavenging by background or associated larger particles
  - The degree to which the agglomerates in bulk nanopowder break during handling and the consequences for the size distribution and structure (morphology) of the particles released to the air.
  - If manufactured particles are emitted to the work room air prior to harvesting, high concentrations of primary manufactured nanoparticles or nano-size agglomerates may initially be present. The relative occurrence in the breathing zone of workers of manufactured nanoparticles as primaries or agglomerates, or as attached to larger background particles will depend on the source characteristics and the coagulation and removal processes during transport from the source to the receptor. The complex influence of electric and magnetic dipoles, turbulence and external force fields on coagulation are very difficult to include in an easy-to-use model like Stoffenmanager Nano.
- Local Control Influence Region. Reduction of transmission could be obtained within the local control influence region by the full or partial enclosure of the source with or with the use of ventilation, local exhaust ventilation, segregation (either completely or partially segregation of the source from the work environment) and separation of the workers (by enclosed cabins or only partial separation). Current scientific knowledge indicates that full enclosure should be similar effective for conventional particles and nanoparticles. Partial enclosure and LEV both seem effective. Effectiveness of segregation and separation can be assumed similar for nanoparticles and conventional particles. However, presently experimental or field data are lacking to substantiate this assumption.
- Dilution. The present simplified two-box model (*i.e.* near-field and far-field approach the same as described for Stoffenmanager) assumes perfect mixing in both compartments with transport between the compartments due to local airflows and turbulence. Consequently, the assumption of perfect mixing may lead to substantial error in case of near field sources.
- Personal behavior. The key determinants of the modifying factor for worker behavior will be the location of the source in relation to the worker, and the amount of latitude the worker has to interact with the source, for example from defined work methods or protocols. This modifying factor is to the same extent taken into account and inter related with activity emission potential. Since much effort is given to derive good work practices *e.g.* ISO (2008b), handling nanomaterials might be more protocolized and thus less prone to personal behavior as compared to handling conventional materials.
- Surface contamination. For surface contamination two processes are relevant, i.e deposition and resuspension.

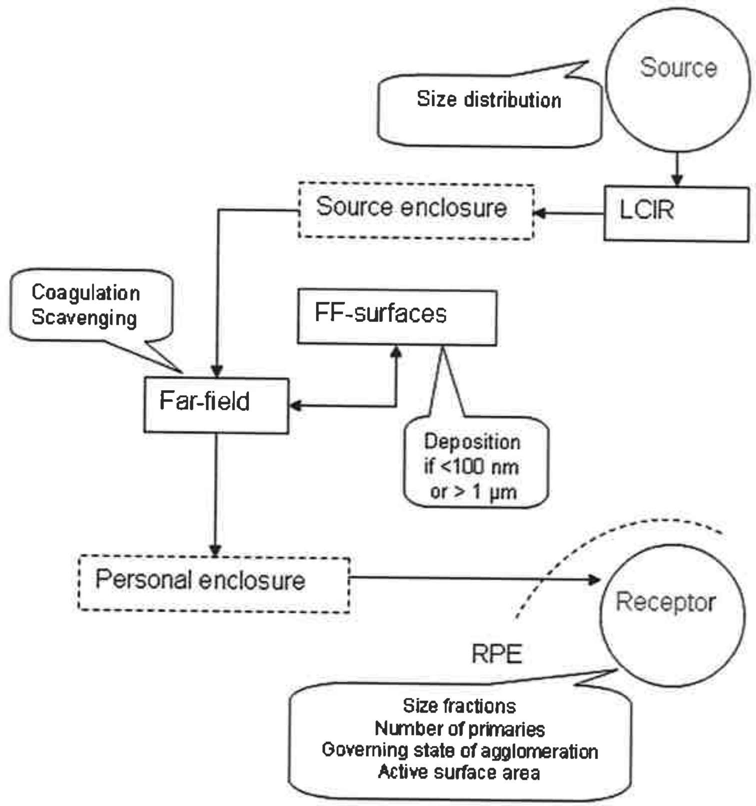
- Respiratory protective devices (RPD). In general the overall efficiency of RPD to reduce levels of exposure will be determined by the interaction between the RPD, work task and the worker (Brouwer *et al.*, 2005).

The illustrations below give a description of the conceptual model for the (a) near field source (b) and the far field source (Schneider *et al.*, (2011)).

Illustration of the conceptual model (a) near field source (b) far field source. The rectangles indicate the compartments, whereas the callouts indicate the transport processes. LCIR = Local Control Influence Region, RPE = Respiratory Protective Devices; FF = Far Field, NF=Near Field.



(a)



(b)

The conceptual source-receptor model for nano-objects described by Schneider *et al.* (2011) can be used as a framework for characterization of exposure in a control-banding tool, *e.g.* similar to the underlying model of the Stoffenmanger for inhalation exposure to 'conventional 'particles (Marquart *et al.*, 2008, Tielemans *et al.*, 2008b). It should be noted that the conceptual nano-model does not intend to be applicable for nanofibers and nanotubes within source domain 'release of primary particles during synthesis (*e.g.* sampling, maintenance, cleaning) because of their extreme shape and agglomeration behavior.

Within the conceptual model described by Schneider *et al.* (2011) two new parameters of exposure are proposed: 'coagulation and scavenging' and 'personal behavior'.

Literature on risk banding

A limited number of publications are available regarding risk banding of nanoparticles. The most important publications regarding risk banding of nanoparticles are discussed below.

Genaidy *et al.* (2009) have performed a qualitative risk analysis applied to carbon nanofiber plant. Within this approach the risk level and subsequently intervention required is based on the level of severity and the level of probability. The interventions proposed for the different risks levels are: implement substantial changes immediately followed by incremental changes, start with substantial changes in the short term, followed by incremental changes, start with incremental changes and then explore substantial changes (if needed), explore incremental changes, and sustain the current status. The descriptions of the actions proposed are rather vague.

Wardak *et al.* (2008) have proposed a control banding approach based on scenarios and risk-triggers defined for exposure and hazard to identify risks and rank the risks. No suggestions of the level of control needed is given, as no risk bands are defined.

Maynard (2006) defined impact indexes and exposure indexes to come to four specific control bands. These control bands are: general ventilation, engineering control, containment and seek specialist advice. This control banding matrix is similar to that used in the implementation of control banding through COSHH Essentials program described by the HSE (1999). Based on the conceptual model described by Maynard (2006) a control banding nanotool was developed by Paik et al. (2008). The control bands resulting from the described probability and severity bands are the same as described by Maynard (2006). The model is evaluated by Zalk *et al.* (2009). A high level of consistency has been found when comparing the CB Nanotool risk level outcomes to expert IH recommendations. It can be seen that there is a tendency for the CB Nanotool's qualitatieve risk assessment approach to err toward the conservative at times; however, IH experts also agree that it is better to err toward over-control rather than under-control.

The Federal Office of Public Health (FOPH) and Federal Office of the Environment (FOEN) have proposed a precautionary matrix for synthetic nanomaterials (Höck et al., 2008). This matrix facilitates trade and industry to identify possible sources of risks in the production, use and disposal of synthetic nanomaterials. Potential dangerous applications can be identified for employees, consumers and environment and measures to protect health and the environment can be taken in cooperation with industry. The outcome of the matrix is a score that will result in an A or B classification. Classification A results in the action 'the nanospecific risks can also be graded as low without further clarification of risks of the nanomaterials'. Classification B results in the action 'possible risks specific to nanomaterials should not be excluded. Further clarification of the risks is needed, or if necessary risk reduction measures must be taken in relation to manufacture, use and disposal, with a precautionary approach in mind.'

Within Stoffenmanager (Marquart *et al.* 2008) the results of the hazard and exposure banding are combined into three priority bands. When a situation is evaluated and a priority band is assigned, Stoffenmanager enables the user to design a risk reduction scenario or control scenario. This option leads to a list of possible control measures that can be taken. The control measures are presented in the order of the so-called 'STOP-principle' (Substitution, Technical measures, Operational measures, Personal protection). The user first has to consider the possible control measures of the first group, before he can go on to the control measures of the second group, etc. As the effect on exposure of the different control measures is included in the Stoffenmanager model, the user is able to estimate the exposure based on the use of the control measure that could be implemented. The same concept might be applicable for Stoffenmanager Nano.