Innovative strategies, methods and tools for occupational risks management of manufactured nanomaterials (MNMs) in the construction industry

CUSTOMIZED CONTROL BANDING APPROACH FOR POTENTIAL EXPOSURE TO MANUFACTURED NANOMATERIALS (MNMS) IN THE CONSTRUCTION INDUSTRY

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1 EXECUTIVE SUMMARY

This document describes the software prototype developed in the SCAFFOLD project. The tool is a customization of Control Banding (CB) using the work done at SCAFFOLD on the assessment and prevention of occupational risks of Manufactured NanoMaterials (MNMs) when used in the construction industry. The tool considers the materials and construction processes treated at Scaffold according to input from SCAFFOLD's reports on risk assessment and risk protection and from SCAFFOLD partners. It can be applied to construction scenarios not studied in SCAFFOLD as well. The allocation of hazard bands is according to the ISO/TS 12901-2 (2014) standard.

The exposure algorithms developed here are strongly based on well-established models, mainly Stoffenmanager and DREAM. In particular, the respiratory exposure algorithm follows the Stoffenmanager source-receptor approach and incorporates modifying factors related to source emission and dispersion of contaminants. The generic exposure is represented as a multiplicative function of type of handling and intrinsic properties of the product. The dermal exposure algorithm is according to the DREAM model. Significant simplifications are applied so that the resulting dermal algorithm requires the minimum possible input. An effort is also made to avoid overlapping of the input data used in the respiratory and dermal exposure algorithms. The ranking of various combinations of exposure and hazard bands in terms of risk follows the approach suggested by Oliveira Nunes (2015). Risk levels are divided into five risk bands according to the BS 8800 (2004) standard.

2 SCOPE

The goal of this work was to develop a new control banding (CB) tool suitable for the occupational risks of MNMs in the construction industry. The work included the following activities:

- Analysis and development of risk scenarios applicable to the construction industry
- Setting occupational exposure limits (performed by FIOH: see Scaffold Public Document SPD7) and occupational exposure bands especially for construction industry workplaces.
- Development of suitable control bands, relative to exposure targets and hazard groups, and appropriate hazard communication policies.
- Testing of the applicability of the Stoffenmanager Nano-tool in the construction work area (performed by FIOH: see Scaffold Public Document SPD10)
- Selection of the PPE [Personal Protective Equipment] used by workers in construction area such as gloves, masks and technical suits, according to nanoparticles risks.

The elaboration of the CB tool also took into account results from other work within the Scaffold project, on risk prevention, risk protection and risk assessment.

CB approaches have long been used for qualitative assessment and management of occupational risks, in the absence of relevant Occupational Exposure Limits. The CB method has been proven particularly useful for providing hazard control guidance to small and medium size enterprises, while larger businesses may use CB strategies for prioritizing hazards and hazard communication. In view of their growing presence in workplaces and the lack of toxicological data for setting up occupational exposure limits, several CB tools have lately been developed for manufactured nanomaterials (MNMs) and associated processes.

The present document describes the Control Banding tool, how it was developed, the underlying theory and assumptions, and how it can be used. In particular, chapter 3 describes the hazards database. Chapter 4 gives the theoretical background for the respiratory exposure and presents the exposure algorithm used here. Chapter 5 gives the theoretical background for the dermal exposure and presents the exposure algorithm used here. Chapter 6 presents the implementation of the algorithms and the databases in Microsoft Excel and describes the software.

3 HAZARD

Respiratory and dermal hazard bands for generic materials can be allocated based on the ISO/TS 12901-2 (2014) standard, which proposes a table of characteristic properties. In addition, Van Duuren-Stuurman et al. (2012) suggest a classification database for nanomaterials to be used when insufficient data are available.
The approach proposed here, employs four options for hazard band allocation in the following order:

- Hazard band allocation for a known material using information provided by the SCAFFOLD partners. The data collection is further discussed in section 3.1.
- Hazard band allocation using the Van Duuren-Stuurman et al. (2012) hazard classification database. Note that this database relates to respiratory hazards. We assume the same classification for dermal hazards.
- Collection of information on the material using the ISO/TS 12901-2 (2014) standard table. The hazard band is allocated based on the worst observed category among the supplied material property classifications. Properties not related to dermal hazards are not taken into account for dermal hazard band allocation. Similarly for respiratory hazard bands.
- Collection of information on the parent material using the ISO/TS 12901-2 (2014) standard table. In this case, the nanomaterial respiratory/dermal hazard bands are taken as plus one of the respective parent bands.

3.1 Data collection on SCAFFOLD materials

In order to assess the hazard potential for the materials used in the SCAFFOLD project specific toxicological data are needed. Data were collected from SCAFFOLD partners (ACCIONA, CEA, FIOH, NETCOMPOSITES and TECNAN) using a list of generic characteristics for each material. The list provided was based on ISO/TS 12901-2 (2014), OECD/ENV/JM/MONO(2009)20/REV and existing CB tools (see Figure 1). The responses cover carrier materials and nanomaterials.

The answers that were collected are presented in Figures 2 – 12. More specifically, in figure 2 the toxicological data for the carrier material from NETCOMPOSITES (Unsaturated polyester resin) are presented. In figure 3 the toxicological data for the nanomaterial 1 from NETCOMPOSITES (dimethyl dihydrogenated tallow ammonium modified bentonite) are presented. In figure 4 the toxicological data for the carrier material from TECNAN (distilled water) are presented. In figure 5 the toxicological data for the nanomaterial 1 from TECNAN (TiO_2) are presented. In figure 6 the toxicological data for the nanomaterial 2 from TECNAN (SiO_2) are presented. In figure 7 the toxicological data for the carrier material from ACCIONA (cement) are presented. In figure 8 the toxicological data for the nanomaterial 1 from ACCIONA (SiO_2) are presented. In figure 9 the toxicological data for the nanomaterial 2 from ACCIONA (Titanium dioxide-sepiolite supported) are presented. In figure 10 the toxicological data for the nanomaterial 1 from ACCIONA (cellulose nanofibers) are presented. In figure 11 the toxicological data for the nanomaterial 2 from ACCIONA (carbon nanofiber) are presented. In figure 12 the toxicological data for the nanomaterial 2 from ACCIONA (TiO_2) are presented.

As noticed in figures 2 to 12, most of the entries that refer to the necessary toxicological data include the notion "Unknown". Assessing the Hazard Band with most of the toxicological parameters being unknown results in high Hazard Band levels. For certain material parameters this yields Hazard Category D, and in the remaining cases we get Hazard Category E. Note that, the material hazard band is derived based on the worst observed category. So if a material has one characteristic property classified as E and the rest classified as A, B and C, the allocated hazard band is E. In many cases, the property entries increasing the hazard class to D and E are the "unknown" ones. The above is also concluded in SCAFFOLD report 4.10 as follows:

"MSDSs of the products do often not give any details (hazardous properties, size or shape) about the nanocomponents and the concentration of the nanomaterial in the product is unclear… If you use the inhalation hazard "unknown" for the nanomaterial, you end up in the hazard band D. This is one big question related to the weaknesses of the Stoffenmanager Nanotool, where almost all the nanomaterials end up in the hazard classes D or E".

For the cases where the NMN used is a well-defined substance (like TiO_2 or SiO_2) the Hazard Bands as assessed by Van Duuren-Stuurman et al. (2012) are used.

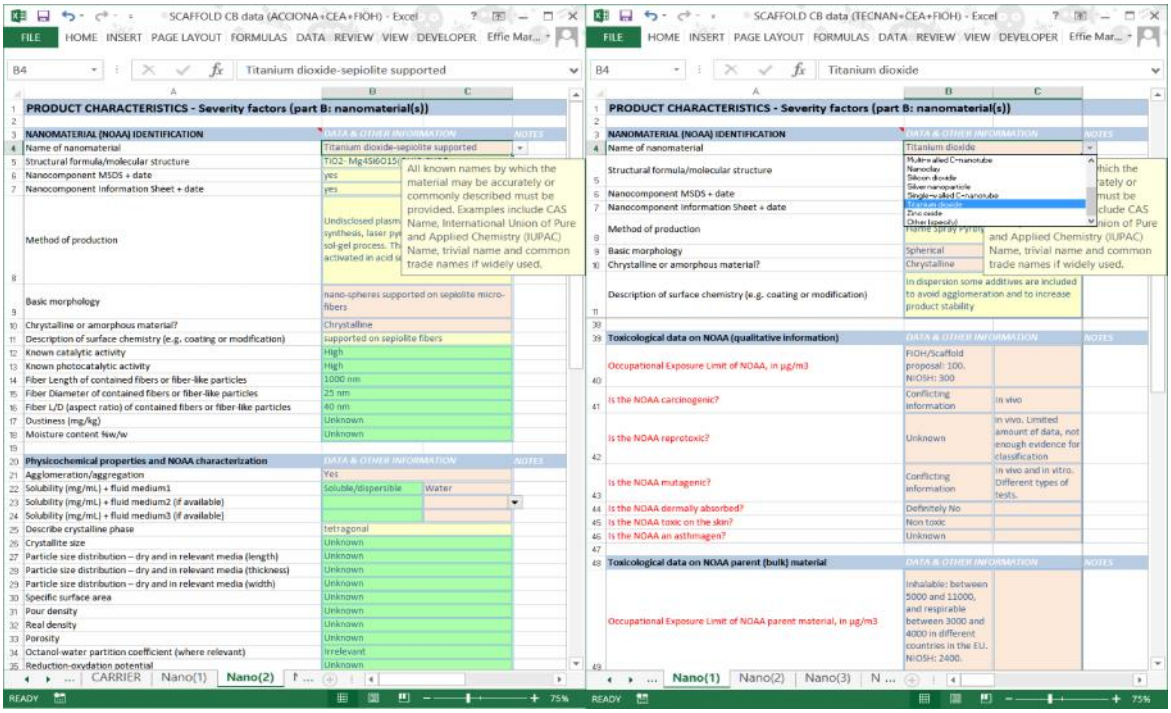

Figure 1 Screenshots of the questionnaire used for the collection of the material data

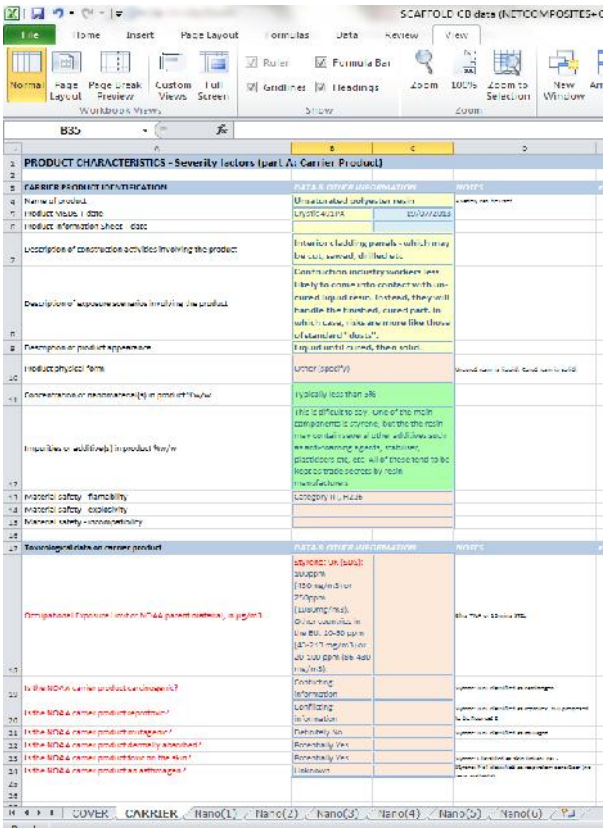

Figure 2 Screenshots of the toxicological data for the Carrier material of NETCOMPOSITES

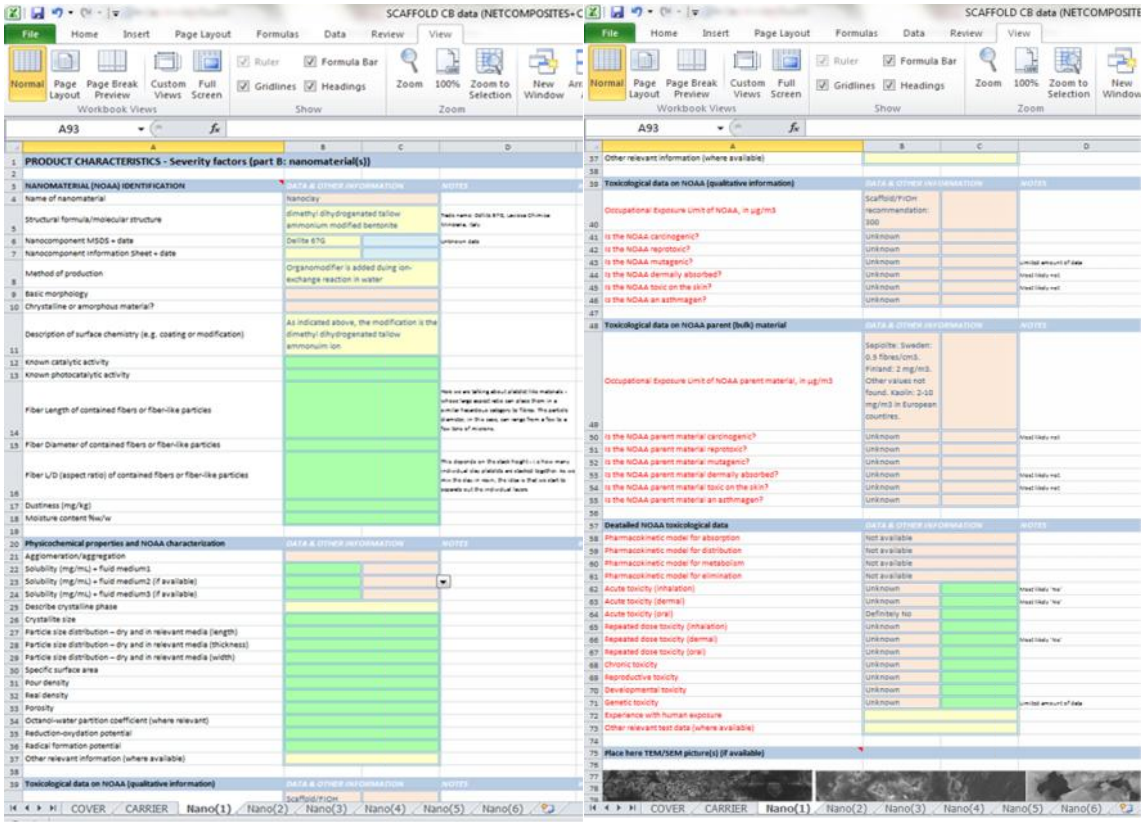

Figure 3 Screenshots of the toxicological data for the Nanomaterial of NETCOMPOSITES

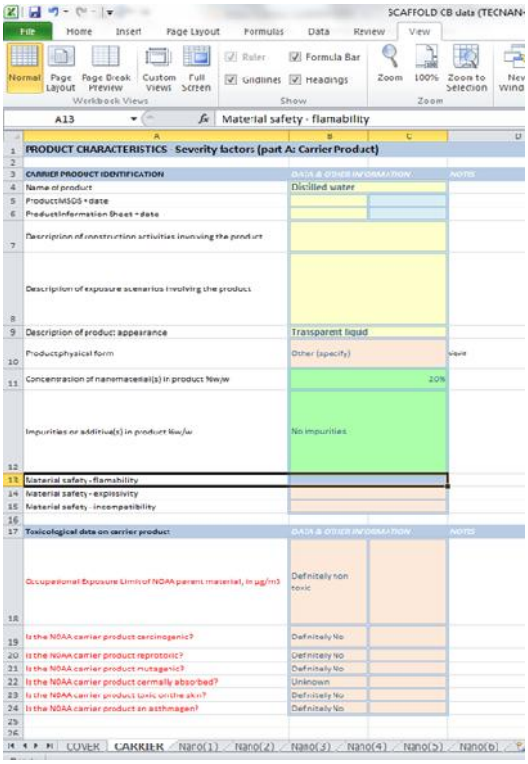

Figure 4 Screenshots of the toxicological data for the Carrier material of TECNAN

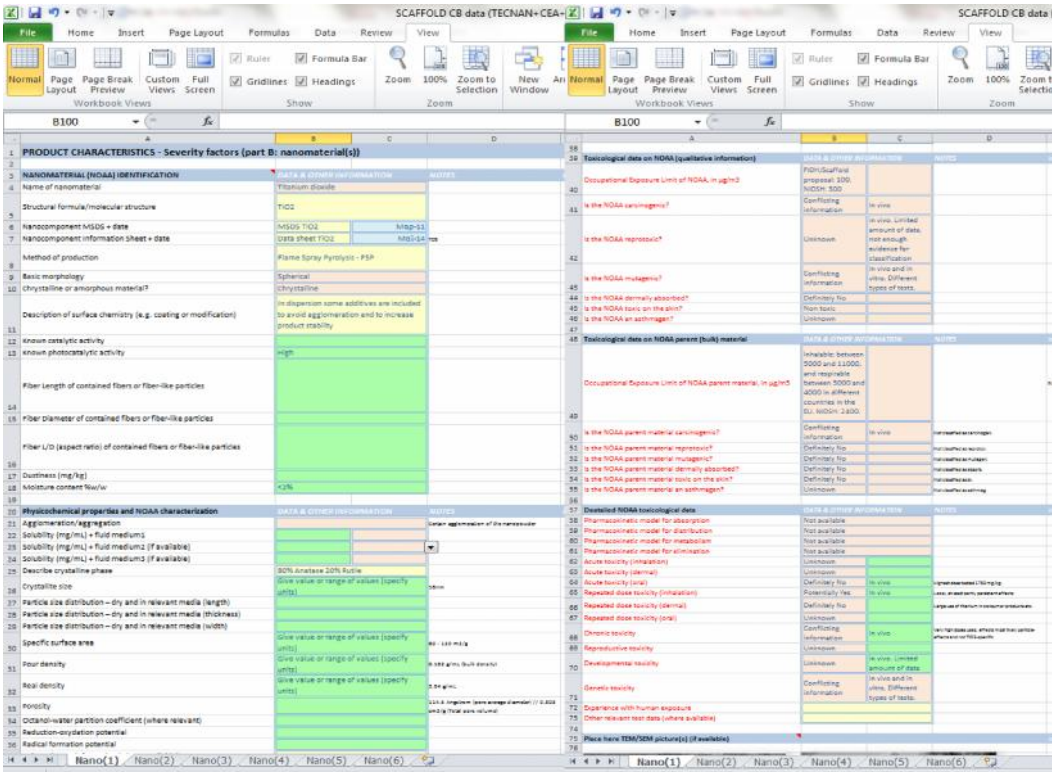

Figure 5 Screenshots of the toxicological data for the Nanomaterial 1 of TECNAN

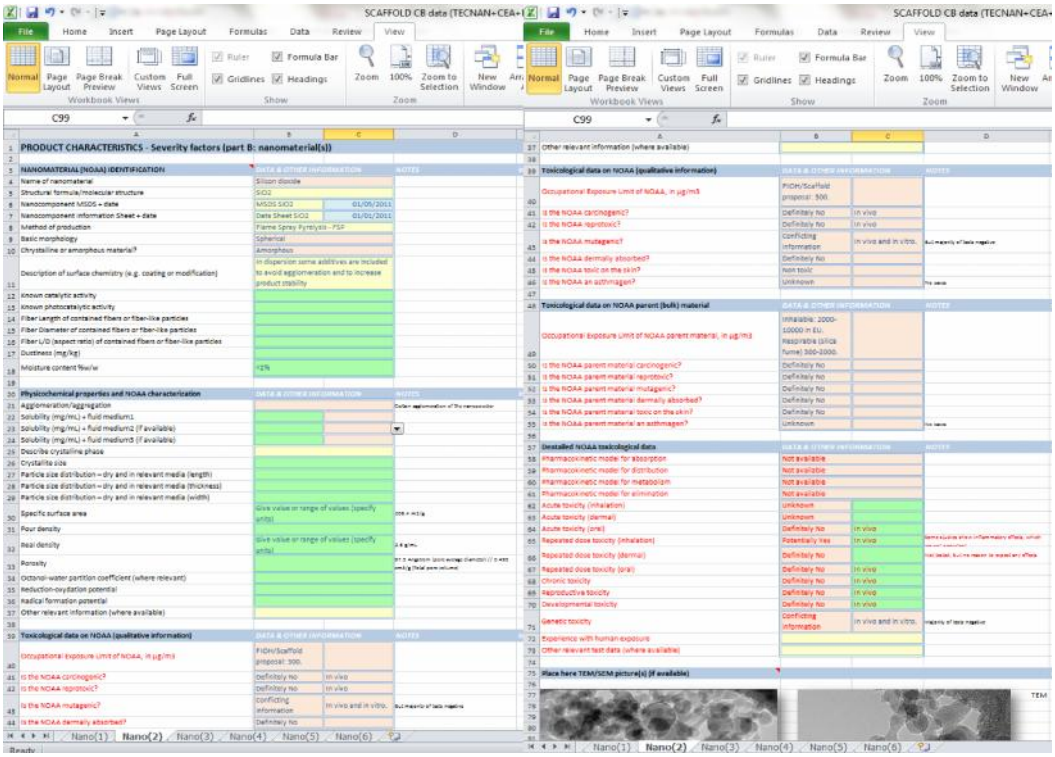

Figure 6 Screenshots of the toxicological data for the Nanomaterial 2 of TECNAN

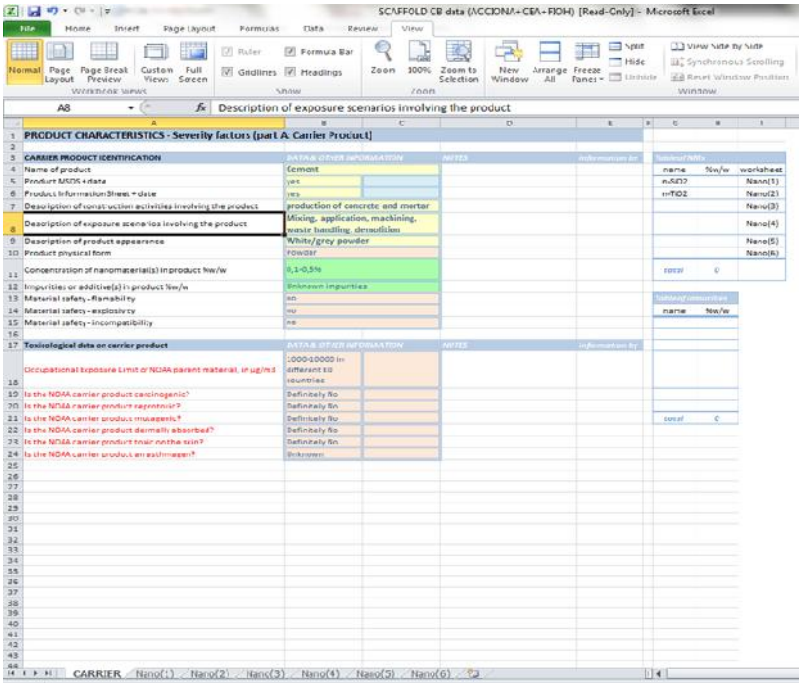

Figure 7 Screenshots of the toxicological data for the Carrier material of ACCIONA

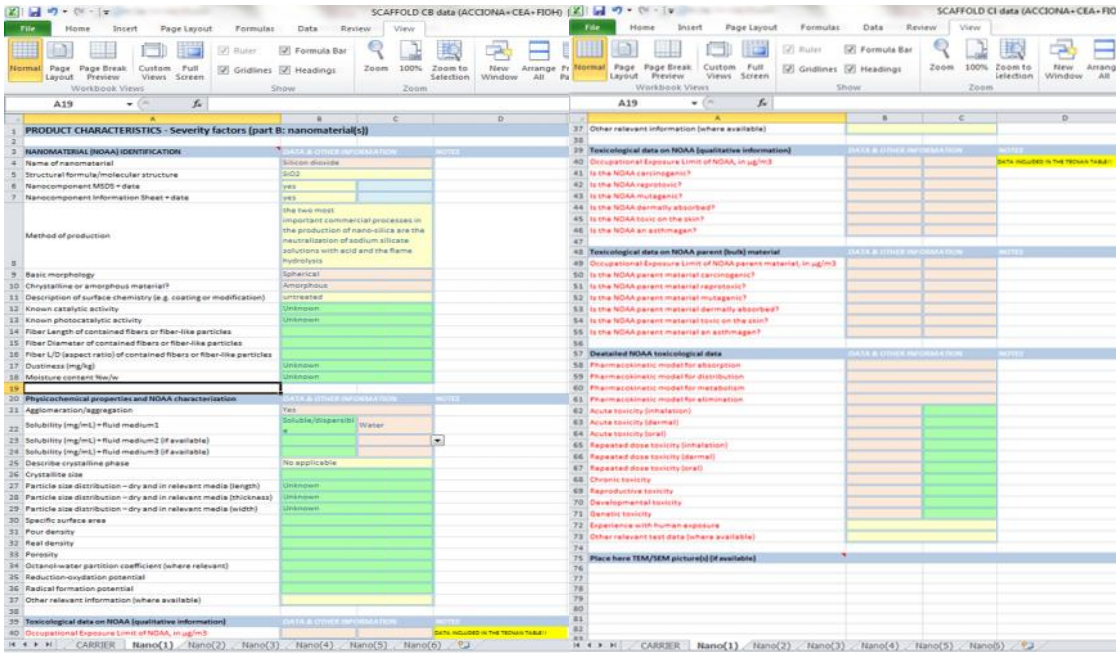

Figure 8 Screenshots of the toxicological data for the Nanomaterial 1 ACCIONA

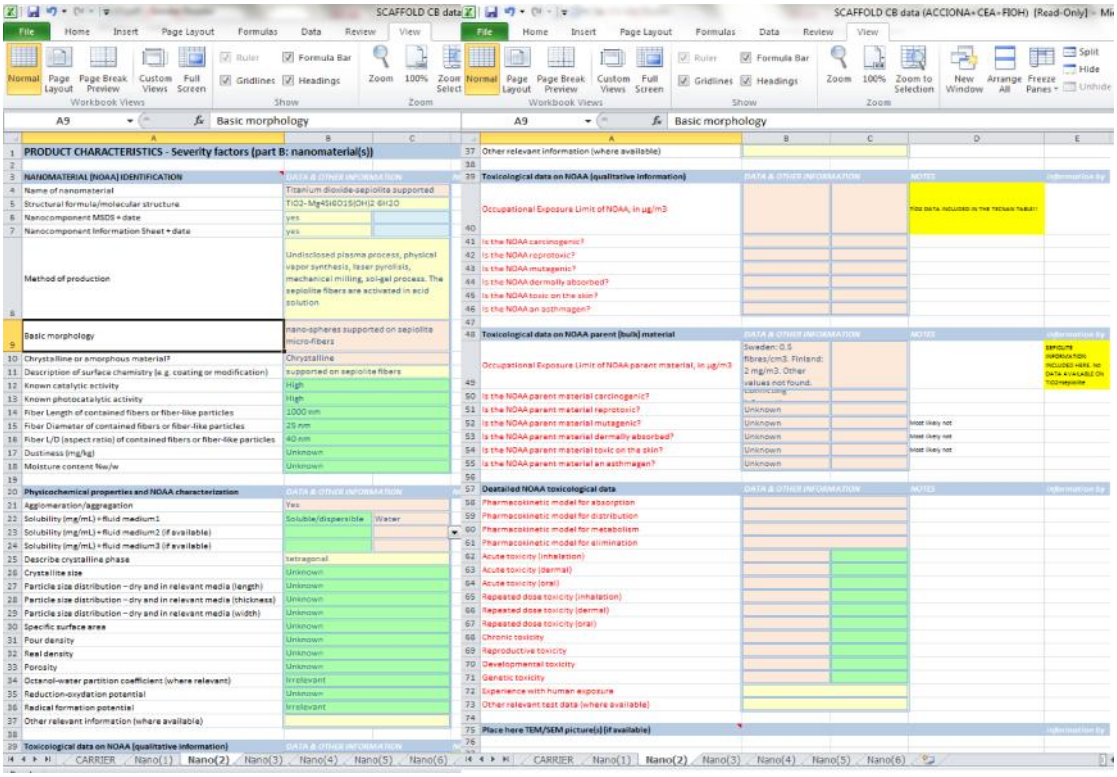

Figure 9 Screenshots of the toxicological data for the Nanomaterial 2 ACCIONA

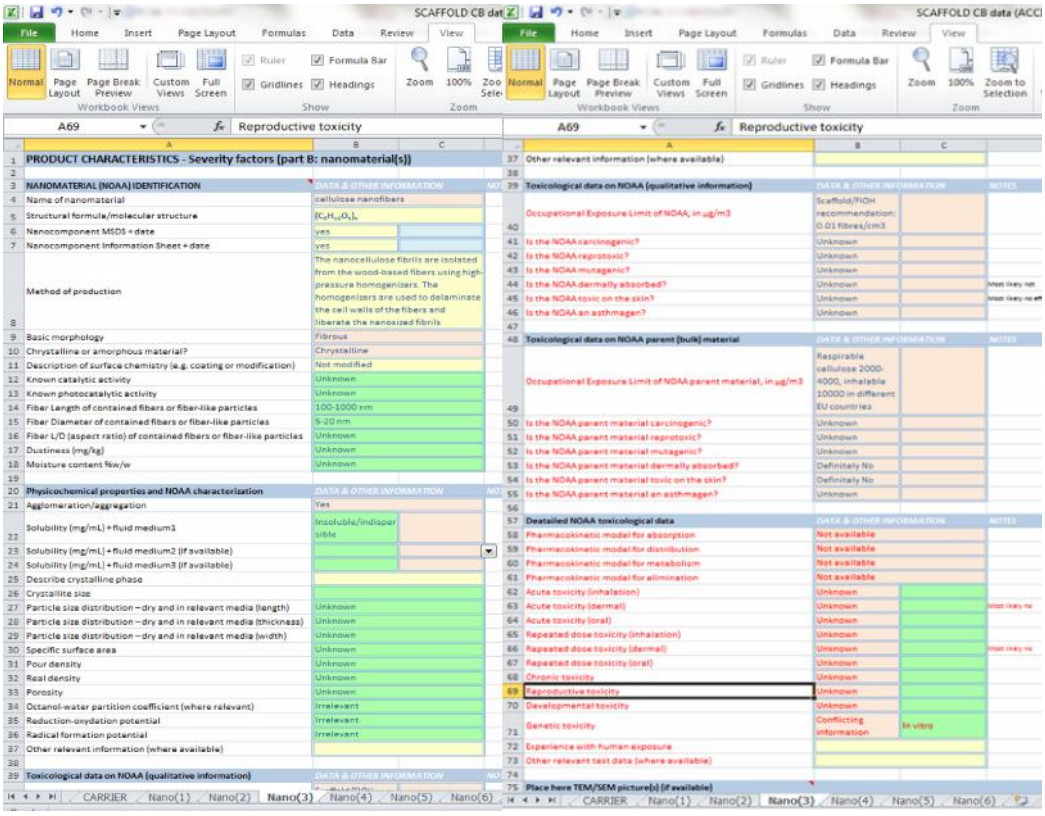

Figure 10 Screenshots of the toxicological data for the Nanomaterial 3 ACCIONA

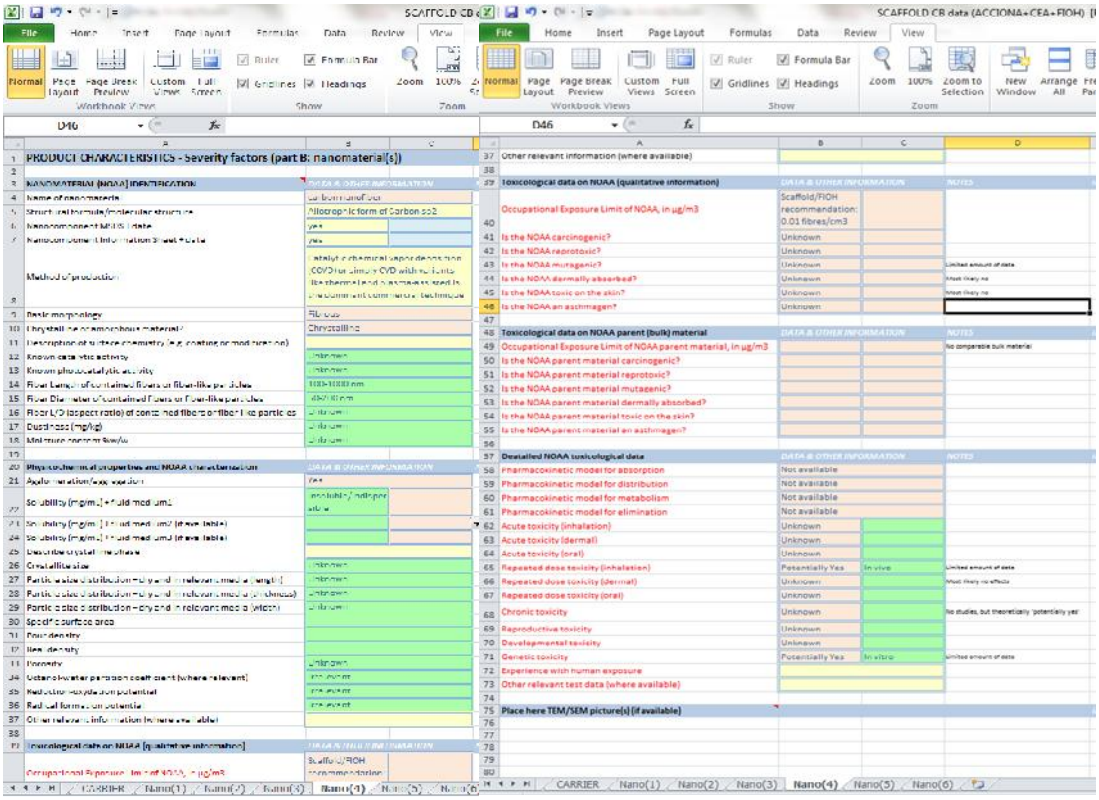

Figure 11 Screenshots of the toxicological data for the Nanomaterial 4 ACCIONA

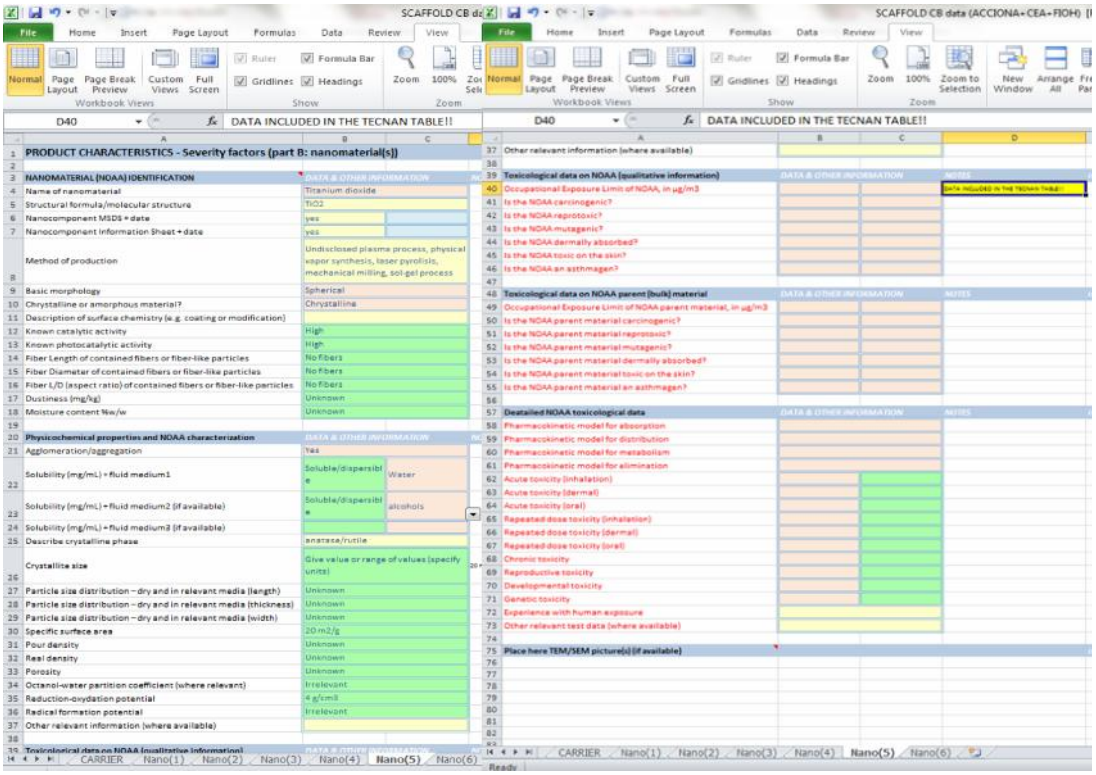

Figure 12 Screenshots of the toxicological data for the Nanomaterial 5 ACCIONA

4 RESPIRATORY EXPOSURE

Respiratory exposure is the most common case of exposure in the construction industry. This can occur through activities generating dust or forming aerosol. Inhalation of hazardous substances can also be followed by ingestion (Scaffold's Guide on Risk Protection, SPD13).

Respiratory exposure to manufactured nanomaterials (MNMs) in the construction industry is assessed according to Van Duuren-Stuurman et al. (2012), Marquart Hans et al. (2008), Tielemans et al. (2008) and the ISO/TS 12901-2 (2014) Standard. Following the Stoffenmanager Nano approach (Van Duuren-Struuman et al., 2012) possible worker exposure situations in the life cycle of nano products are distinguished in four general source domains (Schneider et al., 2011). These are further subdivided into six source domains- to better accommodate the MNOs and corresponding materials used in the Construction Industry- as follows:

SD1. Point or fugitive emission during the production phase prior to harvesting the bulk material (e.g. leaks through connections, seals, etc. during MNO synthesis/incidental release; examples of production processes are flame pyrolysis and chemical vapour condensation);
SD2. Handling and transfer of bulk powdered MNOs (e.g. bagging or dumping of powder);
SD3. Dispersion of solid intermediates or ready-to-use MNO-containing products
SD4. Spraying of ready-to-use nano-products
SD5. Handling of liquid intermediates containing MNO's
SD6. Activities resulting in fracturing and abrasion of MNO-containing end products (e.g. sanding of surfaces).

Source domain SD6 refers to processes that should be treated using a conventional non-nano Control-Banding tool Van Duuren-Stuurman et al. (2012). This is outside the scope of this work.

The activities in the construction industry considered in SCAFFOLD are classified in the six general source domains as shown in Table 1. Accidental scenarios (see grey cells) are not suited for Control Banding assessment.

Table 1 Activities using MNOs in construction

	Substance	SCAFFOLD SCENARIOS		Source Domain
Depollutant mortar	**TiO2**	ES1	Manufacturing NMs	**SD1**
		ES1	Formulations containing MNMs	**SD2**
		ES2	Monolayer rendering application Mortar application (construction site)	**SD2**
		ES3	On site assembly/Machining Machining of the mortar at pilot scale	**SD2**
		ES4	Deconstruction: Demolitions, retrofitting ES4 Demolition of the mortar at pilot/lab scale	**SD6**
		ES5	Accidental fire: MNMs combustion Accidental fire simulation at lab scale	**n.a.**
Self-compacting concrete	**SiO2**	ES6	Manufacturing NMs	**SD1**
		ES7	Concrete mixing for piles, slabs and special structures CASE STUDY Concrete manufacturing/application process	**SD2**

		ES8	On site assembly/Machining; Machining of the concrete at pilot scale	**SD2**
		ES9	Maintaining, demolition or failure of the structure ES9 Demolition of the concrete at pilot/lab scale	**SD6**
		ES10	Accidental fire: MNMs combustion Accidental fire simulation at lab scale	**n.a.**
Coating	**CNF**	ES11	Manufacture in-site (of the coating) ES11 Manufacturing process (coating with CNF)-lab	**SD1**
		ES12	Machining for superficial fitting of other elements Machining the coating pilot scale	**SD2**
		ES13	Maintenance or demolition of the coating ES13 Demolition of the coating at lab scale	**SD6**
		ES14	Accidental fire: MNMs combustion Accidental fire simulation at lab scale	**n.a.**
Self-cleaning coating	**TiO2**	ES15	Preparation, dosification, application of coatings CASE STUDY Coating application (spraying sol-gel)	**SD4**
		ES16	Superficial machining; Machining of the coating at pilot scale	**SD2**
		ES17	Demolition, end of life ES17 Demolition of the coating at lab scale	**SD6**
		ES18	Accidental fire: MNMs combustion Accidental fire simulation at lab scale	**n.a.**
Fire Resistant panels	**Nanoclay**	ES19	Offsite manufacturing CASE STUDY Manufacturing process	**SD1**
		ES20	Fitting of the panels and machining for the superficial installations of other elements Machining of the FR panels at pilot scale	**SD2**
		ES21	Demolition, end of life ES21 CASE STUDY Demolition of the FR panels at lab scale	**SD6**
		ES22	Accidental fire: MNMs combustion Accidental fire simulation at lab scale	**n.a.**
Insulation	**Cellulose**	ES23	Offsite Manufacturing ES23 Insulation manufacturing	**SD1**
		ES24	Fitting of the panels and machining for the superficial installations of other elements ES24 Machining of the insulation panels at pilot scale	**SD2**
		ES25	Demolition, end of life ES25 Demolition of the insulation panels at lab scale	**SD6**
		ES26	Accidental fire: MNMs combustion	**n.a.**

The exposure algorithm used in Stoffenmanager follows a source-receptor approach and incorporates modifying factors related to source emission and dispersion of contaminants. The model is a modification of a model developed by Cherrie and Schneider (1999) and Cherrie et al (1996) as modified by Schneider (2011). Stoffenmanger has introduced some modifications to this model to make it more suitable for use by SME employers.

Exposure is represented as a multiplicative function of type of handling, intrinsic properties of the product, local controls and general ventilation. A general exposure score is calculated according to the following equation

$$B = [(E \cdot H \cdot \eta_{lc\_nf} \cdot \eta_{gv\ nf)}) + (E \cdot H \text{ x } \eta_{lc\_ff} \cdot \eta_{gv\_ff}) + (E \cdot a)] \cdot \boldsymbol{\eta_{ws}} \cdot \eta_{imn} \cdot t_h \cdot f_h \quad (1)$$

where

B : respiratory exposure score;

E: intrinsic emission score for respiratory exposure;

H : handling (or task) score for respiratory exposure;

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;

η_{gv_ff} : multiplier for the effect of general ventilation in relation to the room size on the exposure due to far-field sources;

η_{ws} : multiplier for worker separation;

a : multiplier for the relative influence of background sources;

η_{imm} : multiplier for the reduction of exposure due to control measures at the worker;

t_h : duration of the handling;

f_h: frequency of the handling;

Further simplification made in this tool is to assume that *far-field sources* and background emissions are relative small compared to the near field sources. As mentioned in the Stoffenmanager model (Marquart Hans et al (2008)) this means that for the far-field source the emission due to a period of evaporating, hardening or dying does not include products with vapour pressure >10Pa. Similarly it has been chosen to ignore the background source assuming that the activities of interest (construction activities involving use of nanomaterials) are characterized by high direct emission. As a result, the exposure index B used in the Scaffold model is given by

$$B = E \cdot H \cdot \eta_{lc\_nf} \cdot \eta_{gv\,nf)} \cdot \eta_{imn} \cdot \eta_{ws} \cdot t_h \cdot f_h \qquad \textbf{(2)}$$

where:

B : respiratory exposure score;

E: intrinsic emission score for respiratory exposure;

H : handling (or task) score for respiratory exposure;

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_{imm} : multiplier for the reduction of exposure due to control measures at the worker;

η_{ws} : multiplier for worker separation;

t_h : duration of the handling;

f_h: frequency of the handling

Parameters E, H, t_h,f_h characterize the basic scenario and are not subject to modification through control measures. Of course it might be possible to decrease the frequency and the duration of a particular task. This kind of measures is not considered as such that can by adopted by employees of SME construction firms. More general management and expert involvement is required. The SCAFFOLD tool can however be used for evaluation of such measures.

Parameters η_{lc} η_{gv} η_{imm} on the other hand, depend on the adopted control measures and are used to quantify the effect of these measures.

4.1 Intrinsic emission for Respiratory Exposure

The intrinsic emission is a substance related parameter. Different formulae are followed according to the source domain.

Note that, for the source domain SD1, it is assumed that emission potential does not vary between different types of MNO for the same process. Therefore, the substance emission potential is included in the score for handling and not further included in the algorithm. This is in agreement Van Duuren-Stuurman et al. (2012).

4.1.1 Intrinsic emission for liquids

MNOs dispersed in a liquid are processed in the source domains SD4 and SD5. The substance emission potential (score) E is then given by the following the product:

$$E = E_1 \cdot E_2 \cdot E_3 \quad \textbf{(3)}$$

where:

E_1: score depending on the weight fraction of the MNOs (Table 2);

E_2: score depending on the percentage dilution of the substance in water (Table 3), and

E_3: score depending on the viscosity of the liquid (Table 4)

Table 2 . Respiratory scores for weight fraction E_1 (table adapted from Marquart et al., 2008).

Category	Score
Undiluted	1
50–99%	0.75
10–50%	0.3
1–10%	0.05
0.01–1%	0.005
< 0.01%	0.00005
Unknown	1

Table 3 Respiratory scores for dilution of MNO in water E_2 (table adapted from Marquart et al., 2008).

Category	Score
Undiluted	1
55–99%	0.75
10–50%	0.3
1–10%	0.05
0.01–1%	0.005
< 0.01%	0.00005
Unknown	1

Table 4 Respiratory scores for viscosity of liquids E_3 (table adapted from Marquart et al., 2008)

Category	Score
Liquids with low viscosity (like water)	1
Liquids with medium viscosity (like oil)	0.3
Liquids with high viscosity (like resin, syrup, paste)	0
Unknown	1

4.1.2 Intrinsic emission for solids

Solid MNOs are processed in the following source domains SD2 and SD3. The substance emission potential of solid MNOs E is given by the product of the scores for weight fraction, dustiness, and moisture content, according to the formula:

$$E = E_1 \cdot E_2 \cdot E_3 \quad \textbf{(4)}$$

where:

E_1: score depending on the weight fraction (Table 2);

E_2: score depending on the dustiness (Table 5 and Table 6 for nano-powders and granules/flakes, respectively); and

E_3: score depending on the moisture content (Table 7).

Van Duuren-struuman et al. (2012) suggest that until more is known about the dustiness of nanopowders, the highest dustiness class ought to be used for dusts, i.e to use E_2=1 if solid is dust.

Table 5 Respiratory scores for intrinsic emission of powders E_2 (table adapted from Marquart et al., 2008).

Intrinsic emission parameter	Explanation - Indicative dustiness test results (respirable fraction)	Score
Very High	>500mg kg^{-1}	1
High	150-500 mg kg^{-1}	0.3
Medium	50 – 150mgkg^{-1}	0.1
Unknown		1

Table 6 Scores for intrinsic emission of granules /flakes E_2 (table adapted from Marquart et al., 2008).

Category	Examples	Score
Granules or flakes that may fall apart and crumble	washing powder, sugar or fertilizer	0.03
Firm granules or flakes	firm polymer granules, granules covered with a layer of wax, bound fibers, such as in cotton. No dust emission without intentional breakage of the product	0.01
Unknown		0.03

Table 7 Respiratory scores for moisture content of solids E_3 (table adapted from Marquart et al., 2008; Van-Wendel-de-Joode et al., 2003)

Category	Description	Score
Dry product (<5% moisture content)	Dry powder or granules/flakes	1
5–10% moisture content	Powder or granules/flakes of which the particles stick to each other while the dry form is not sticky less dusty than the dry product	0.1
Sticky, waxy or moist product (>10% moisture content)	Powder or granules/flakes that is/are clearly wet; sticky or waxy products	0.01
Unknown		1

4.2 Handling – Activity emission potential for Respiratory Exposure

The Handling – Activity emission potential *H* is a score related to the process. Different multiplier data are considered according to the source domain.

The source domain SD1 involves (new) production processes that are not described in the handling categories included in the generic Stoffenmanager. It is difficult to define Handling scores for these

processes as the tasks performed mostly concern controlling the (closed) process. During a production process, particles might, for example, be released unintentionally through leaks. Despite the lack of exposure data, conservative relative multipliers are defined for this source domain that is in line with the precautionary principle. Doing this gives the user the opportunity to perform a risk assessment for these processes (Table 8).

The scores proposed by Stoffenmanager for handling of liquids and solids are reported in Table 9 and Table 10, respectively. Note that, the production processes of Table 8 and the process categories of Table 9 and Table 10 are limited to those of interest to the construction industry.

Table 8 Respiratory scores for handling for SD1 (table adapted from Marquart et al., 2008).

Production process	Description	Score
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 substrates	1
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 to higher	0.3

Table 9 Respiratory scores for handling of liquids (table adapted from Marquart et al., 2008).

Category	Examples	Score
Handling of liquids at high pressure resulting in substantial generation of mist or spray/haze	Spraying of product (using high-pressure or spray painting) fogging a 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 liquids using low pressure and low speed in large or medium quantities	Mixing/diluting liquids by stirring, manually drawing off or pouring product, painting of casings using a roller or a brush	0.1

Table 10 Respiratory scores for handling of solids (table adapted from Marquart et al., 2008).

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 objects 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, mechanical 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 heavily 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, weighting of product (kilograms)	1
Handling of products in closed containers	Transport/shifting of barrels, bottles, or plastic bags	0

4.3 Duration and frequency of Respiratory Exposure

Tables 9 and 10 report the scores for the duration and frequency of exposure, respectively. Note that, these scores are derived from the fraction of work time that an individual worker performs

the task and is therefore exposed to the hazardous substance. The software also includes the option of inputting the time fraction, as in some cases, the duration and the frequency of the work might be difficult to interpret (SCAFFOLD report SPD10 on StoffenManager Nano-tool).

Table 11 Scores for duration of exposure t_h (table adapted from Marquart et al., 2008).

Parameter	Score
1–30 min a day	0.06
0.5–2 h a day	0.25
2–4 h a day	0.50
4–8 h a day	1.00

Table 12 Scores for frequency of exposure f_h (table adapted from Marquart et al., 2008).

Parameter	Score
1 day a year	0.01
1 day a month	0.05
1 day per 2 weeks	0.10
1 day a week	0.20
2–3 days a week	0.60
4–5 days a week	1.00

4.4 Modifying the Respiratory Exposure Score through protective measures

As discussed before the remaining coefficients η_{lc}, η_{gv}, η_{ws}, η_{imn} in Equation 2 refer to existing or proposed protection measures. In particular, η_{gv} refers to general ventilation dependent on room size; η_{lc} refers to local controls; η_{ws} refers to worker separation; and η_{imn} refers to scores for protection by PPE. Table 13 gives the suggested scores for general ventilation controls, Table 14 gives the suggested measures for localized controls. Table 15 gives the scores for worker separation measures, while Table 16 provides the suggested scores for the various PPEs.

Table 13 Scores for general ventilation (table adapted from Marquart et al., 2008).

Room size	No general ventilation (0.3–1 ACH)	Mechanical and/or natural ventilation (3 ACH)	Spraying booth (>10 ACH)
Volume <100 m3	10.00	3.00	0.10
Volume 100–1000 m 3	3.00	1.00	0.30
Volume >1000 m3	1.00	1.00	1.00
Work performed outside	n.a.	1.00	n.a.

Table 14 Scores for localized controls (table adapted from Marquart et al., 2008).

Local control measure	Description	Score
No control measures at the source		1.000
Use of a product that limits the emission	Wetting a powder, spraying of water	0.300
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 dust system	0.300
Containment of the source	The source is fully contained however, no local exhaust ventilation is used within the containment;	0.300
Containment of the source with local exhaust ventilation	Containment of the source in combination with local exhaust ventilation, e.g. a fume cupboard	0.030
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

Table 15 Scores for separation (or personal enclosure) of the worker (table adapted from Marquart et al., 2008).

Separation measure	Scores
The worker does not work in a cabin	1.000
The worker works in a cabin without specific ventilation system	0.100
The worker works in a separated (control) room with independent clean air supply	0.030

Table 16 Scores for Respiratory Personal Protection Equipment (PPE)

Local Control measure	Score
None	1
FFP2 filtering half masks	0.40
FFP3 filtering half masks	0.20
P2 replaceable filter Half Mask	0.40
P3 replaceable filter Half Mask	0.20
A1P2 combined half mask	0.20
A1P3 combined half mask	0.10
Full-Face masks with P3 filters	0.10
A powered filtered device incorporating a TH1 hood	0.20
A powered filtered device incorporating a TH2 hood	0.10
A powered filtered device incorporating a TH3 hood	0.05

4.5 Respiratory Exposure Bands

Assessment of the exposure determining parameters (see sections 4.1 to 4.3) along with the control measures modifying factors (see section 4.4) determine an overall exposure score *B* according to Equation 2. The range of possible Exposure scores is divided into ten bands as shown in Table 17. The reason for considering ten exposure bands is to be able to quantitatively distinguish between the improvements (reduction of exposure) of the various protective measures. This point is further discussed in Chapter 6.

Table 17 Respiratory Exposure Bands

Respiratory Exposure Band	Respiratory Exposure Score	
	Lower	Upper
1	0	0.000005
2	0.000005	0.00005
3	0.00005	0.0005
4	0.0005	0.005
5	0.005	0.001
6	0.001	0.05
7	0.05	0.1
8	0.1	5
9	5	100
10	100	∞

5 DERMAL EXPOSURE

Penetration of the skin during construction activities is still under investigation. If the skin is intact, it provides a good barrier. Nanoparticles can, however, penetrate through damaged or diseased skin and end up in the systemic circulation (Scaffold's Risk Protection Guide, SPD13).

Dermal exposure to manufactured nanomaterials (MNMs) in the construction industry is assessed according to the DREAM method (Van-Wendel-de-Joode et al., 2003, 2005). The DREAM method provides structured, semi-quantitative assessment of dermal exposure for chemical and biological agents. SCAFFOLD's report SPD6 presented the method in detail and tested the applicability of the method to the scenarios considered in the SCAFFOLD project.

The DREAM method stars by assessing the potential dermal exposure, that is the exposure of naked skin without any protective clothing. The potential exposure score for annual exposure is quantified as the following formula:

$$B_0 = (R_E + R_T + R_T) \cdot t_h \cdot f_h \quad (5)$$

where:

R_E : score depending on exposure through the emission route;
R_D : score depending on exposure through the deposition route;
R_T : score depending on exposure through the transfer route;
t_h : score depending on duration of the handling; and
f_h: score depending on frequency of the handling.

The method assigns a weight factor for each route, making the exposure through emission 3 times more important that through deposition and transfer. In the present work, and considering the SCAFFOLD scenarios, it is assumed that exposure via transfer is negligible. In addition, for reasons of simplicity, the exposure through deposition is modeled as a fraction, r_D, of the emission exposure. Therefore, Equation 5 becomes:

$$B_0 = R_E \cdot (1 + r_D) \quad \textbf{(6)}$$

Table 18 gives the scores for fraction r_D.

Table 18 Dermal exposure scores for the importance of deposition over emission

Case	Score
High importance	1/3
Medium importance	0.1
No deposition occurs	0

According to DREAM, the exposure through emission is then formulated as follows:

$$R_E = 3 \cdot E \cdot \sum_{i=1}^{9} s_i \cdot P_i \cdot I_i \quad \textbf{(7)}$$

where:

E : score for intrinsic emission potential;

P_i : score for probability of emission on body part i;

I_i : score for intensity of emission on body part i; and

s_i : surface factor of body part i.

Note that, the DREAM method considers 9 different body parts, namely the head, the upper arms, the forearms, the hands, the front torso, the back torso, the lower body, the lower legs and the feet.

As explained in section 5.2, the intensity of emission is herein considered processes specific, and treated similarly to the handling activity emission potential defined in section 4.2 for Respiratory Exposures . Therefore, a single score is assigned to the intensity I, and Equation 7 becomes:

$$B_0 = 3 \cdot E \cdot I \cdot P \cdot (1 + r_D) \quad \textbf{(8)}$$

where $P = \sum_{i=1}^{9} s_i \cdot P_i$ and it is the overall probability of emission P on the entire body.

5.1 Intrinsic emission for Dermal Exposure

The intrinsic emission potential is calculated as a product based on the physical characteristics of the material involved in the process. Different formulae are followed according to the phase of the substance, in agreement with the DREAM method (Van-Wendel-de-Joode et al., 2003, 2005).

For SD1, it is assumed that the emission potential does not vary between different types of MNO for the same process (Van Duuren-Stuurman et al, 2012). Therefore, the substance emission potential is included in the multiplier for exposure intensity, as in section 4.1.

5.1.1 Intrinsic emission for liquids

For MNOs dispersed in a liquid (see SD4 and SD5), the substance emission potential (score) for dermal exposure is given by the following the product:

$$E = E_1 \cdot E_2 \cdot E_3 \cdot E_4 \quad \textbf{(9)}$$

where:

E_1: score depending on the weight fraction of the MNOs (Table 19);
E_2: score depending on the percentage dilution of the substance in water (Table 20), and
E_3: score depending on the boiling point temperature of the substance (Table 21); and
E_4: score depending on the viscosity of the liquid (Table 22).

Table 19 Dermal scores for weight fraction E_1 (table adapted from Van-Wendel-de-Joode et al., 2003).

Category	Score
Undiluted	1
<1%	0.1
1–90%	0.3
90–99%	1
Unknown	1

Table 20 Dermal scores for dilution of MNO in water E_2 (table adapted from Van-Wendel-de-Joode et al., 2003).

Category	Score
Undiluted	1
<1%	0.1
1–90%	0.3
90–99%	1
Unknown	1

Table 21 Dermal scores for boiling point temperature E_3 (table adapted from Van-Wendel-de-Joode et al., 2003).

Category	Score
Tb < 50°C	3
50 < Tb < 150°C	1
Tb > 150°C	0.3
Unknown	3

Table 22 Dermal scores for viscosity of liquids E_4 (table adapted from Van-Wendel-de-Joode et al., 2003).

Category	Score
Liquids with low viscosity (like water)	1
Liquids with medium viscosity (like oil)	1.75
Liquids with high viscosity (like resin, syrup, paste)	3
Unknown	3

5.1.2 Intrinsic emission for solids

The substance emission potential for dermal exposure to solid MNOs (see SD2 and SD3), is given by the product of the scores for weight fraction, dustiness, and moisture content, according to the formula:

$$E = E_1 \cdot E_2 \cdot E_3 \quad \textbf{(10)}$$

where:

E_1: score depending on the weight fraction of the MNOs (Table 19);

E_2: score depending on the dustiness of the solid MNOs (Table 23); and
E_3: score depending on the sticky-waxy-moist of the solid MNOs (Table 24).

Table 23 Dermal scores for dustiness of solids E_2 (table based on Van-Wendel-de-Joode et al., 2003)

Category	Score
Granules or flakes	1
Powder with medium dustiness (50–150 mg/kg)	1
Powder with high dustiness (150–500 mg/kg)	3
Powder with very high dustiness (>500 mg/kg)	3
Powder with unknown dustiness	3

Table 24 Dermal scores for stickiness of solids E_3 (table based on Van-Wendel-de-Joode et al., 2003)

Category	Score
Dry product (<5% moisture content)	1
5–10% moisture content	1
Sticky, waxy or moist product (>10% moisture content)	1.75
Unknown	1.75

5.2 Intensity of emission for Dermal Exposure

Similarly to the respiratory exposure (see Chapter 4), the intensity of emission for dermal exposure is considered processes-specific. So, a score is defined for each one of the process cases considered here. The multiplier values range between 0 and 10, in accordance to the DREAM multipliers which ranged between 1 (Small amount (<10 % of body part)) to 10 (Large amount (≥50% of body part)). Table 25, Table 26 and Table 27 give the multipliers proposed here for the intensity of dermal exposure (handling multipliers). The multipliers of Table 25 include the intrinsic emission potential for dermal exposure.

Table 25 Dermal scores for handling for SD1 (based on Marquart et al. (2008); Van Duuren-Stuurman et al. (2012)).

Production process	Description	Score
Mechanical reduction (machining)	Machining (turning, milling) of larger products to create smaller products	3.00
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 substrates	1.00
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	0.30
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 to higher	0.30

Table 26 Dermal scores for handling of liquids (based on Marquart et al. (2008); Van Duuren-Stuurman et al. (2012)).

Category	Examples	Score
Handling of liquids at high pressure resulting in substantial generation of mist or spray/haze	Spraying of product (using high-pressure or spray painting) fogging a product producing a visible mist spraying of Nanofilm spray	10
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	1.00
Handling liquids using low pressure and low speed in large or medium quantities	Mixing/diluting liquids by stirring, manually drawing off or pouring product, painting of casings using a roller or a brush	0.033

Table 27 Dermal scores for handling of solids (based on Marquart et al. (2008); Van Duuren-Stuurman et al. (2012)).

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 objects with compressed air	10.00
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	3.00
Handling of products with medium speed or force, which leads to some dispersion of dust	Manual dumping of bags, mechanical mixing or sieving of medium quantities of product	1.00
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 heavily contaminated with product	0.30
Handling of products with low speed or little force or in medium quantities (several kilograms)	Handling of contaminated objects, scooping of (kilograms) product, weighting of product (kilograms)	0.10
Handling of products in closed containers	Transport/shifting of barrels, bottles, or plastic bags	0.00

5.3 Probability of emission for Dermal Exposure

To simplify the tool developed here for the construction industry, the following five cases are considered for dermal exposure due to emission:

1. Only hands
2. Mainly hands (also above waist and head)
3. Hands, above waist and head
4. Bellow waist
5. All the body

The probability of emission P on the entire body, for each one of these cases is then calculated using the body part surface factors proposed by (Van-Wendel-de-Joode et al., 2003). The resulting probability scores P_j are reported on Table 14, where $j \in \{1,2,3,4,5\}$ denotes one of the five cases. The multipliers for the exposed body parts range between 10 and 3, while the respective multipliers proposed in DREAM are: 10 (almost constantly (or ≥50% of task duration)) and 3 (repeatedly (or 10–50% of task duration)). In the case of occasional exposure (or <10% of task duration), we herein take this exposure as negligible.

Table 28 Dermal scores for the five cases of exposed body parts (surface factors from Van-Wendel-de-Joode et al., (2003))

Body part	**Surface factor**	**1 Only hands**	**2 Mainly hands (also above waist and head)**	**3 Hands, above waist and head**	**4 Bellow waist**	**5 All the body**
head	0.69		3.0	10.0		3.0
upper arms	0.67		3.0	10.0		3.0
forearms	0.53		7.0	10.0		3.0
hands	0.47	10.0	10.0	10.0		3.0
front torso	1.22		7.0	10.0		3.0
back torso	1.22					3.0
lower body	2.43				3.0	3.0
lower legs	1.15				10.0	3.0
feet	0.63				10.0	3.0
P_j	**9.01**	**4.7**	**21.03**	**35.8**	**25.09**	**27.03**

5.4 Duration and frequency of Dermal Exposure

The dermal exposure scores used for duration and frequency of exposure are the same as for respiratory exposure (see section 4.3).

5.5 Modifying the Dermal Exposure Score through protective measures

The actual exposure can be significantly lower compared to the potential exposure due to the use of personal protection equipment such as gloves, hyvecs, boots etc. The DREAM method calculates the actual exposure score as the sum of the products of protective measures multipliers and the potential exposure scores:

$$B = \sum_{i=1}^{9} s_i \cdot B_{0,i} \cdot n_i \quad \textbf{(11)}$$

where

$B_{0,i}$: potential exposure score for body part *i*

n_i : clothing factor for body part *i*

The nine body parts defined by Van-Wendel-de-Joode et al. (2003) are herein grouped into five sets. Table 29 shows that, according to the case of exposed body parts, one or more of these sets does not require protective clothing.

Table 29 Proposed personal protection equipment for skin (based on the selected body parts)

	i hands	ii torso/arms	iii lower body	iv feet/lower legs	v head
1. Only hands	see Table 30				
2. Mainly hands (also above waist and head)	see Table 30	see Table 31			see Table 31
3. Hands, above waist and head	see Table 30	see Table 31			see Table 31
4. Bellow waist			see Table 31	see Table 31	
5. All the body	see Table 30	see Table 31	see Table 31	see Table 31	see Table 31

The clothing factor depends on the material of the glove/cloth and the frequency of replacing it. For gloves, DREAM proposes additional considerations, i.e. whether they are connected well to clothing or arms, if a second pair of gloves used and how frequently these are replaced, or if a barrier cream is used. The clothing factor formula used here is the following:

$$n_i = t_i \cdot f_i \cdot g_i \quad \textbf{(12)}$$

where:

t_i : score for the type of protective cloth (see Table 30 and Table 31 for gloves and other clothes, respectively)

f_i : score for the frequency of protective cloth replacement (see Table 32)

g_i : score for the use of inner pair of gloves, equal to 0.3 if inner gloves are applied and equal to 1 in all other cases. Note that, looking at the DREAM multiplies for this entry, it is only worth to consider inner gloves replaced daily.

Table 30 and Table 31 report the simplified options and the multipliers used in the SCAFFOLD CB tool, taking into account the work of Van-Wendel-de-Joode et al. (2003).

Table 30 Scores for gloves t_H (based on Van-Wendel-de-Joode et al. (2003))

Type of gloves	multiplier
No gloves	1
Woven clothing	0.3
Non-woven permeable, not connected well to clothing or arms	0.3
Non-woven permeable connected well to clothing or arms	0.1
Non-woven impermeable connected well to clothing or arms	0.03
Non-woven impermeable, not connected well to clothing or arms	0.09

Table 31 Scores for clothing other than gloves $t_i, i \neq H$ (based on Van-Wendel-de-Joode et al. (2003))

Type of clothing	multiplier*
No clothing	1
Woven clothing	0.09
Non-woven permeable	0.03
Non-woven impermeable	0.009

* multipliers include protection factor 0.3 (Van-Wendel-de-Joode et al. (2003))

Table 32 Score for replacement frequency for dermal PPEs f_i (from Wendel-de-Joode et al. (2003))

Replacement frequency	multiplier
Single use	0.3
Daily	1
Weekly	3
Monthly	10

5.6 Dermal Exposure Bands

Assessment of the exposure determining parameters (see sections 5.14.1 to 5.44.3) along with the control measures modifying factors (see section 5.5) determine the overall actual exposure score *B* (Equation 11). According to Van-Wendel-de-Joode et al. (2003), the range of possible exposure scores is divided into seven dermal exposure categories (Table 33).

6 RISK LEVEL CATEGORIZATION

A combination of specific Hazard Band and a Specific Exposure band represent a level of occupational risk. Different risk levels are considered here for respiratory and dermal risks. The following discussion focuses on the respiratory risks. For respiratory exposure we have considered N_E=10 Exposure bands and N_H=5 Hazard bands there are 50 combinations of Hazard and Exposure bands as shown in Figure 13.

Table 33 Dermal Exposure Bands (from Van-Wendel-de-Joode et al. (2003))

Dermal Exposure Category	Dermal Exposure Band	Dermal Exposure Score	
		Lower	Upper
No exposure	**1**	0	10^{-10}
Very low	**2**	10^{-10}	10
Low	**3**	10	30
Moderate	**4**	30	100
High	**5**	100	300
Very high	**6**	300	1000
Extremely high	**7**	1000	∞

		HAZARD				
		1	**2**	**3**	**4**	**5**
EXPOSURE	**1**					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
	9					
	10					

Figure 13 Risk Matrix consisting of 50 combinations of Hazard and exposure bands.

These combinations ought to be ranked among themselves to define relative risk bands and identify the need for necessary risk –reducing measures, as well as, the initial and final risk levels. As it has been already mentioned in the corresponding section, we have considered so many exposure bands so that the effect of the application of different sets of protective measures is visible to the user.

To rank the various combinations of exposure and hazard bands in terms of risk we follow the approach suggested by Nunes (2015). According to this approach each combination of two risk contributors corresponds to a quantitative risk level (RL) normalized from 1 to 100 percent according to the following relationship:

$$RL = \frac{w_H \log(H_i) + w_E \log(E_j)}{w_H \log(N_i) + w_E \log(N_j)} \cdot 99 + 1 \qquad \textbf{(13)}$$

where

RL= Risk Level (from 1 to 100%)

i –index over the Hazard bands (1,…,N_H)

j --index over the Exposure bands (1,…,N_E)

N_H -- number of Hazard bands (=5)

N_E -- number of Exposure bands (=10)

w_H, w_E – weighting factors for risk contributors Hazard and Exposure respectively.

If both Hazard level and Exposure level are equally important (w_H = w_E = 1) then Equation 13 provides the Risk Matrix shown in Figure 14.

		HAZARD				
		1	**2**	**3**	**4**	**5**
EXPOSURE	**1**	1	19	29	36	42
	2	19	36	46	54	59
	3	29	46	57	64	70
	4	36	54	64	71	77
	5	42	59	70	77	82
	6	46	64	74	81	87
	7	50	68	78	85	91
	8	54	71	81	89	94
	9	57	74	84	92	97
	10	59	77	87	94	100

Figure 14 Risk Matrix with equal importance of Hazard and Exposure bands

The risk matrix shown in Figure 14 assigns a distinct risk level to each and every combination of Hazard and Exposure bands. Furthermore it satisfies the obvious rule that "two risk levels with same band of one of the risk contributors are ranked according to the other risk contributor". For example, if $RL(E_j,H_i)$ denotes the risk level associated with Exposure band E_j and Hazard band H_i Equation 13 ensures that:

$$RL(8,1) < RL(8,2) < RL(8,3) < RL(8,4) < RL(8,5)$$ (see Figure 14).

Consideration of this fine mesh of Exposure / Hazard combination and relative ranking ensures that the effect of two different control (protective) measures will be distinguishable since that they will usually result in different final risk levels. Application of a risk control measure is affecting only the exposure band since the Hazard band depends on the physical, chemical and toxic properties of the nanomaterial and these are not affected by the possible protective measure considered by the proposed Control Banding tool. For this reason we consider the Exposure band to be more important in defining the corresponding risk level.

The effect of this consideration is shown in Figure 15 where the risk levels have been calculated by Equation 13 with:

$$w_H,=1 \text{ and } w_E=3$$

Risk Matrix of Figure 15, for example, assigns a higher RL to the combination (E=2, H=1) than to (E=1, H=2).

		HAZARD				
		1	**2**	**3**	**4**	**5**
EXPOSURE	**1**	1	9	14	17	20
	2	25	33	38	41	44
	3	39	47	52	55	58
	4	49	57	62	65	68
	5	57	65	70	73	76
	6	63	72	76	80	82
	7	69	77	82	85	88
	8	74	82	86	90	92
	9	78	86	90	94	96
	10	81	89	94	97	100

Figure 15 Risk Matrix with Exposure band three times more important than the Hazard band.

To improve the communication characteristics of the tool, the 100 risk levels have been divided into five risk zones corresponding to those suggested by the BS 8800 (2004). The risk levels responding to each risk band are given in Table 34 and they have been subjectively assessed by the authors of this report.

With the adoption of the five risk zones and the corresponding colour scheme the Control Band Risk Matrix of Figure 3 becomes as shown in Figure 16.

For dermal exposure we have N_E=7 Exposure bands and N_H=5 Hazard bands, yielding 35 combinations of Hazard bands and Dermal Exposure bands. Similarly to respiratory risks, dermal risk levels are calculated using Equation 13. Dermal risk bands are allocated according to Table 34.

Table 34 Risk Bands according to BS 8800 (2004)

RISK BANDS			
Risk Level	**LOWER**	**UPPER**	**Tolerability: Guidance on necessary action and timescale**
1—Very Low/Acceptable	0	25	These risks are considered acceptable. No further action is necessary other than to ensure that the controls are maintained
2—Low /Tolerable	25	60	No additional controls are required unless they can be implemented at very low cost (in terms of time, money and effort). Actions to further reduce these risks are assigned low priority. Arrangements should be made to ensure that the controls are maintained
3—Medium	60	75	Consideration should be given as to whether the risks can be lowered, where applicable, to a tolerable level, and preferably to an acceptable level, but the costs of additional risk reduction measures should be taken into account. The risk reduction measures should be implemented within a defined time period. Arrangements should be made to ensure that the controls are maintained, particularly if the risk levels are associated with harmful consequences
4—High	75	90	Substantial efforts should be made to reduce the risk. Risk reduction measures should be implemented urgently within a defined time period and it might be necessary to consider suspending or restricting the activity, or to apply interim risk control measures, until this has been completed. Considerable resources might have to be allocated to additional control measures. Arrangements should be made to ensure that the controls are maintained, particularly if the risk levels are associated with extremely harmful consequences and very harmful consequences
5—Very High / Unacceptable	90	100	These risks are unacceptable. Substantial improvements in risk controls are necessary, so that the risk is reduced to a tolerable or acceptable level. The work activity should be halted until risk controls are implemented that reduces the risk so that it is no longer very high. If it is not possible to reduce risk the work should remain prohibited

		HAZARD				
		1	**2**	**3**	**4**	**5**
EXPOSURE	**1**	1	9	14	17	20
	2	25	33	38	41	44
	3	39	47	52	55	58
	4	49	57	62	65	68
	5	57	65	70	73	76
	6	63	72	76	80	82
	7	69	77	82	85	88
	8	74	82	86	90	92
	9	78	86	90	94	96
	10	81	89	94	97	100

Figure 16 Risk Matrix for Exposure/Hazard band combinations showing the five risk zones of Table 34 and the fine relative risk levels of Equation 13

7 DESCRIPTION OF THE CONTROL BANDING TOOL

Based on the previous theoretical background we developed a Control Banding prototype as an XML-based macro-enabled Microsoft Excel 2013 workbook. The final file is also compatible with Microsoft Excel 2010, while Excel 2007 cannot handle some of the dynamic lists used in the tool.
The Control Banding tool has built-in databases for hazard bands for known compounds, exposure scores, protection measure scores etc, and the exposure algorithms presented in the previous chapters. The tool consolidates the work done in SCAFFOLD, and also includes options for generic scenarios not considered in the project, while they comply with the assumptions made for the typical construction-related activities.

The Control Banding tool is organized as follows:

- ***Cover***: A welcome worksheet with links to the other worksheets (see Figure 17)
- ***HazardBand***: this worksheet guides the user to fill-in the properties of the nanomaterial. There are different options and questions according to the information that the user can provide (see Figure 18, Figure 19 and Figure 20). All the choices are provided in built-in drop down lists. Error messages are also provided to help the user. The worksheet includes two message boxes, one for help and another to reset (clear) the worksheet.
- ***ExposureBand***: this worksheet guides the user to fill-in the process data, along with information on the intrinsic exposure (see Figure 21 and Figure 22). The worksheet is linked to hidden databases and the user response is input to the exposure algorithms for the calculations of respiratory and dermal exposure scores, without the use of protection measures (see Figure 23). The worksheet includes two message boxes, one for help and another to reset (clear) the worksheet.
- ***Measures***: this worksheet supports the selection of protective measures to reduce dermal and respiratory exposures. For the former, the clothing options are according to the exposed body parts specified in worksheet ExposureBand. The worksheet includes two message boxes, one for help and another to reset the worksheet. In this case, the reset option does not clear the table, but rather provides the options to set the table to highest and lowest protection schemes available in the tool. Figure 24 shows the message boxes. Figure 26 shows the result of choosing the highest actual exposure by not using protective equipment. Clearly, the scores and the exposure bands for Figure 23 and Figure 25 are exactly the same. Figure 26 shows that the scores can be reduced and we move to lower exposure bands when protective equipment is selected. Scores are calculated automatically as the user selects protection options using the exposure algorithms built in the tool.
- ***RiskMatrices***: this worksheet shows the risk matrices for respiratory and dermal exposure, and highlights the combination of hazard bands and exposure bands (with and without protective measures). shows the two risk matrices with the assessment results for respiratory and dermal risks. The risk levels are quantified using Equation 13, whereas the

fraction w_H/w_E is defined by the user. In the scenario of Figure 27, the bands for respiratory and dermal hazards are assigned to levels C and D, respectively. The respiratory exposure bands are 9 and 6 without and with the introduction of protection measures, respectively. The risk level is 80 and 73 without and with the measures, respectively. The resulting risk band without protection is “4-High”, and reduces to “3-Medium” when the user-specified protection is applied.

The authors considered integrating the pre-assessment risk knowledge method developed during the iNTegRisk project in the present prototype, so that the level of uncertainties is quantified and information researches are oriented. In iNTegRisk Deliverable 1.3.1.1 the goal was to improve risk management for SMEs dealing with nanotechnologies and to develop reference methods and documents for self-assessment. A questionnaire was proposed by TÜV, with four sets of questions on Organizational, Material, Exposition and Hazards aspects. Normalized weights were assigned to each question and each aspect, to calculate the Total Knowledge Fraction score. Four knowledge classes were considered based on this score, namely little knowledge, some knowledge and excellent knowledge.

The questions on *organizational aspects* involve e.g. the presence of risk and/or OHS managers etc. in the company. This set of questions is irrelevant to control banding. *Exposition aspects* refer to information that can be extracted from the exposure scenario, such as the type of process, the duration and frequency of handling (see sections 4.2, 4.3, and 5.2 to 5.4). This information is expected to be provided with high degree of certainly. Information on *material aspects* refers to material physical properties, collected in the tool intrinsic emission data. A lot of effort is spent on requesting this information in a practical and descriptive manner (see sections 4.1 and 5.1). A significant amount of information on the *nanomaterial hazards* is not expected to be available (see Chapter 3). The primary cause for this unavailability is that toxicological research on manufactured nanomaterials is still at a quite early stage. The target group considered in this work consists of practitioners in small and medium size construction companies, not involved in the design of future toxicological experiments.

In conclusion, the authors acknowledge the work done on developing a pre-assessment risk knowledge method in iNTegRisk project, but consider that the TÜV questionnaire would not add to the present control banding tool.

Figure 17 Cover worksheet: Welcome screen

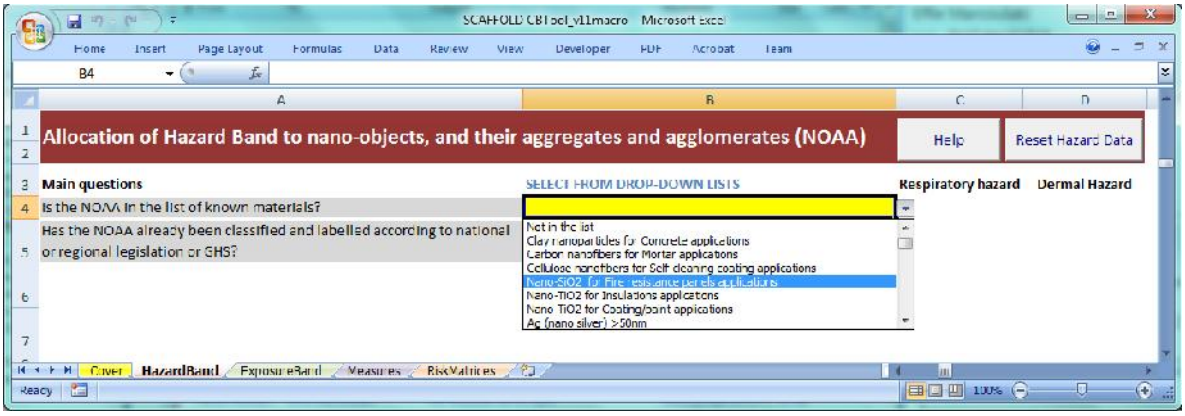

Figure 18 HazardBand worksheet: list of available materials, including SCAFFOLD substances and other MNM's

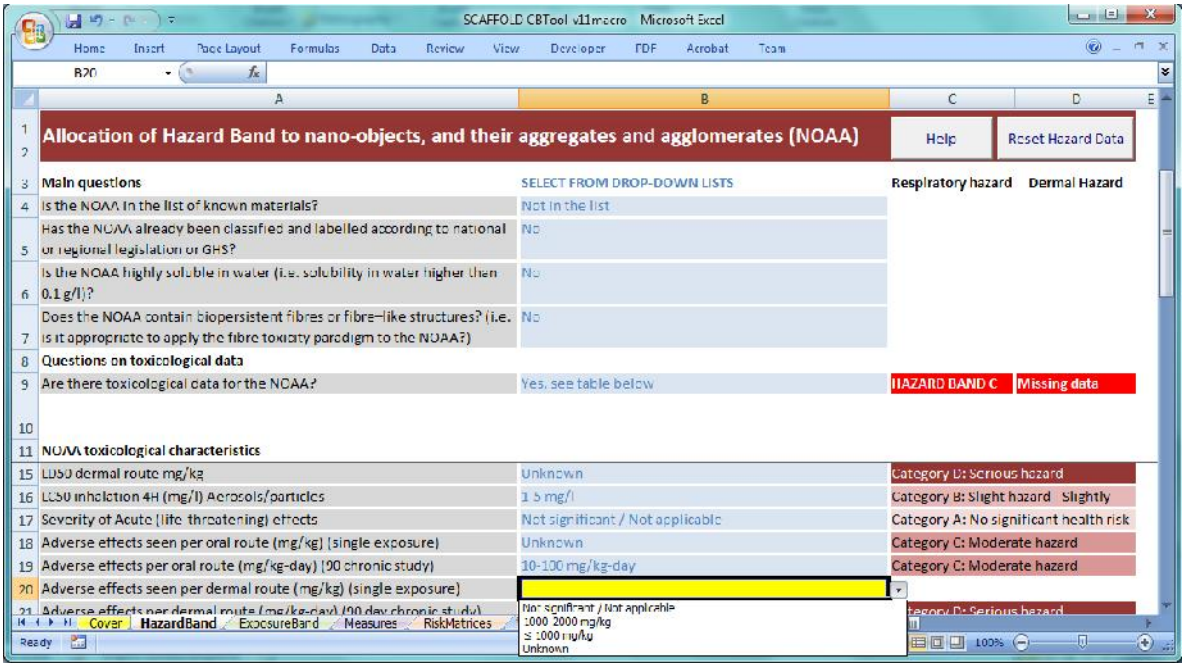

Figure 19 HazardBand worksheet: Filling-in the toxicological data – dermal hazards' data are still missing

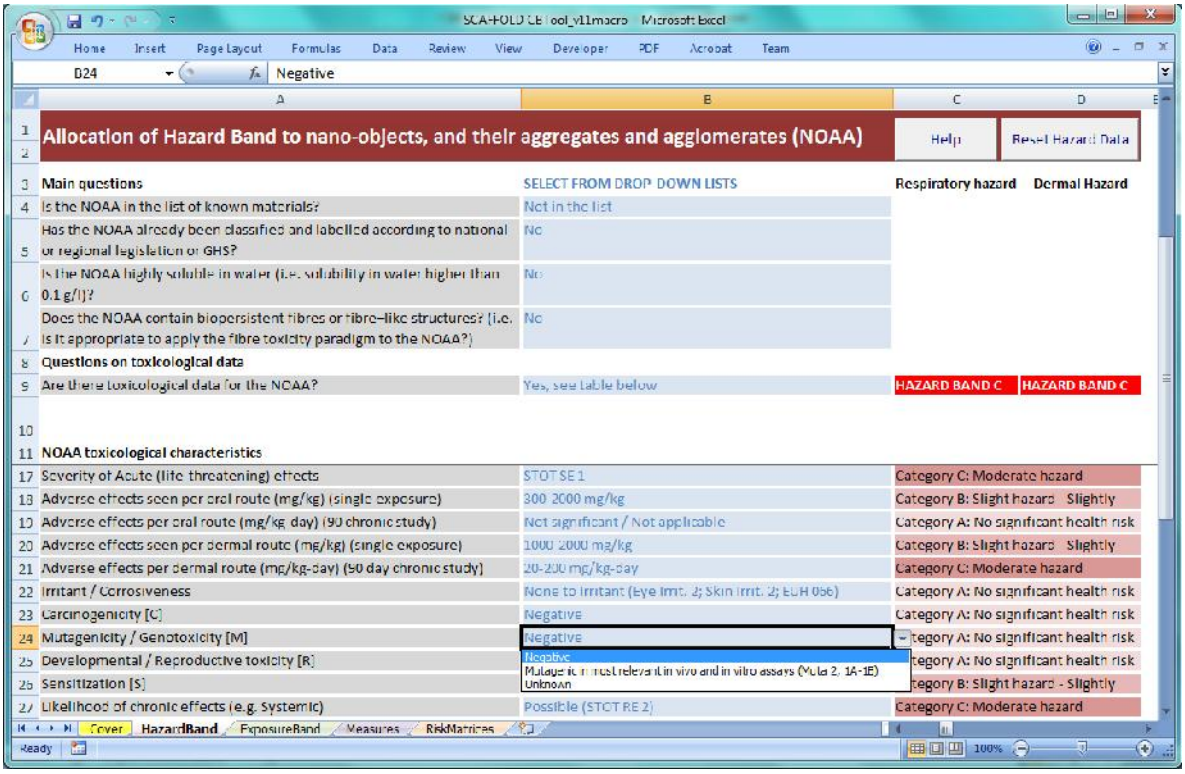

Figure 20 HazardBand worksheet: Location of hazard band when sufficient toxicological data are available

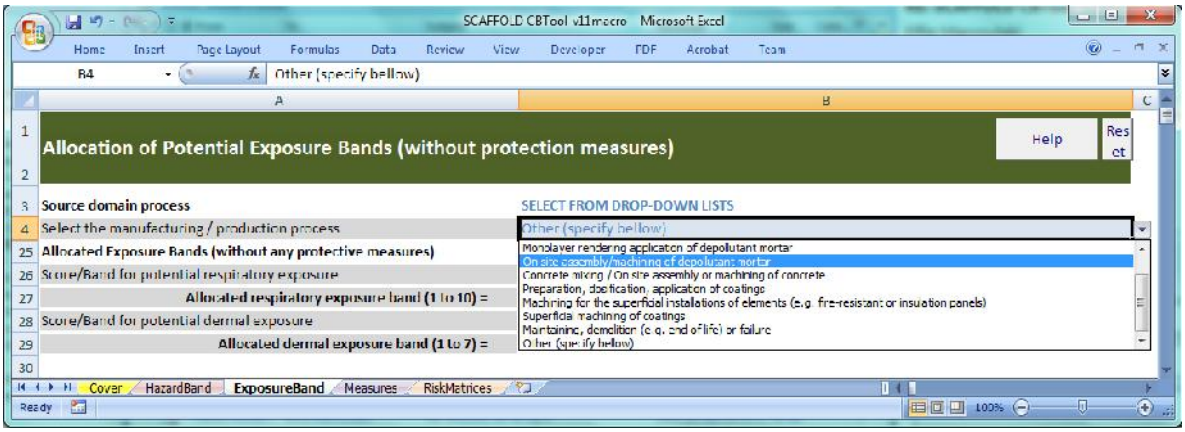

Figure 21 ExposureBand worksheet: Selection of manufacturing/production process, including SCAFFOLD processes

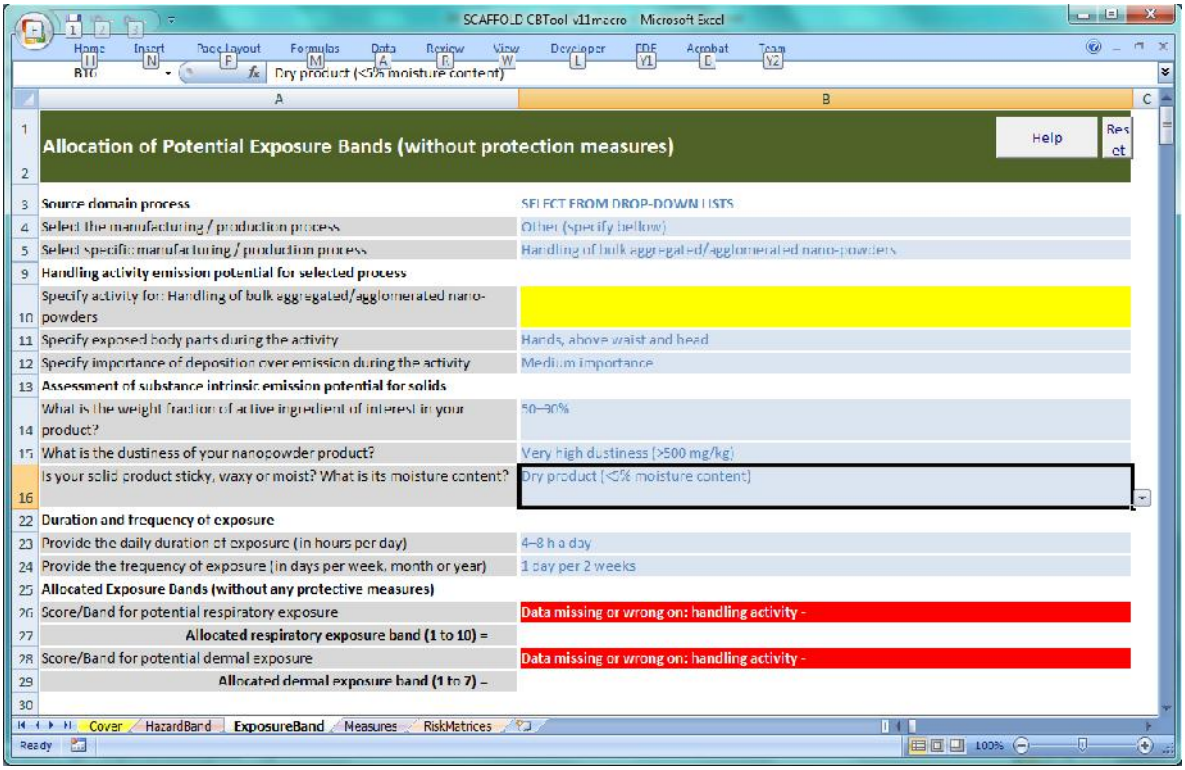

Figure 22 ExposureBand worksheet: Filling-in data for a generic (other, non-SCAFFOLD) process

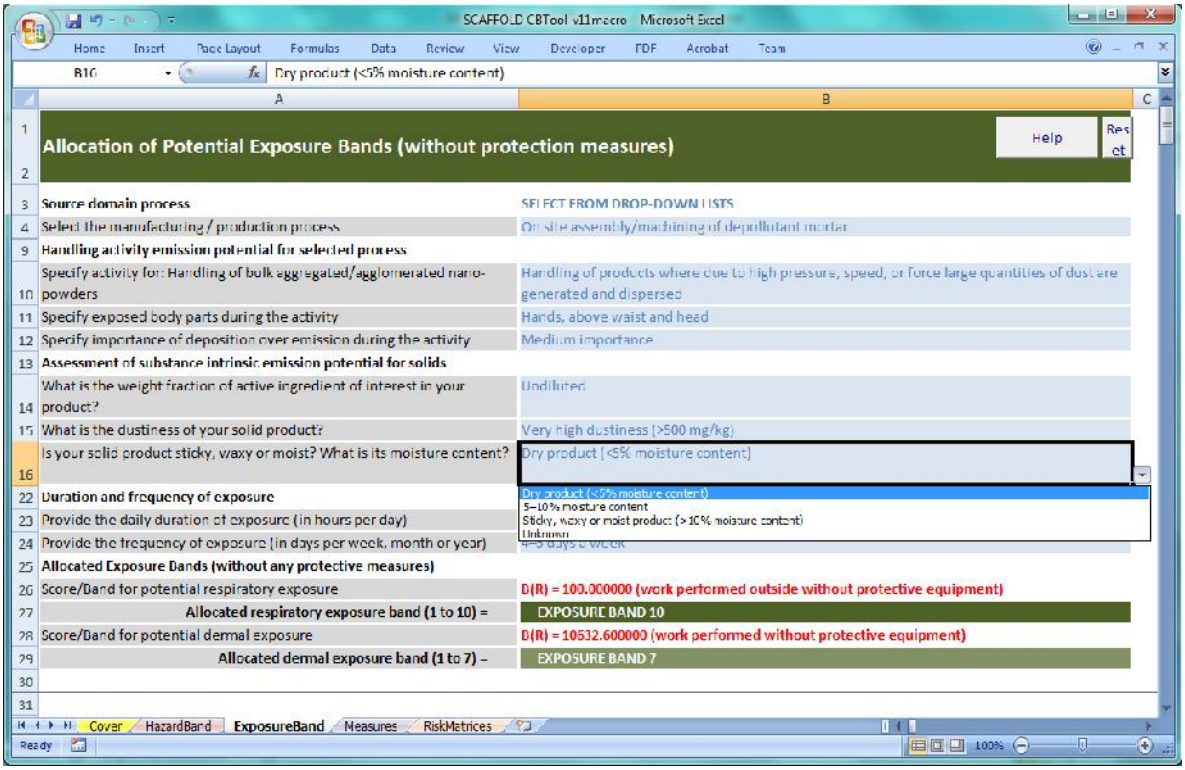

Figure 23 ExposureBand worksheet: Calculated exposure scores for a highly risky process

Figure 24 Measures worksheet: The reset message box, the message box with the two reset options and a message box urging the user to correct the space conditions

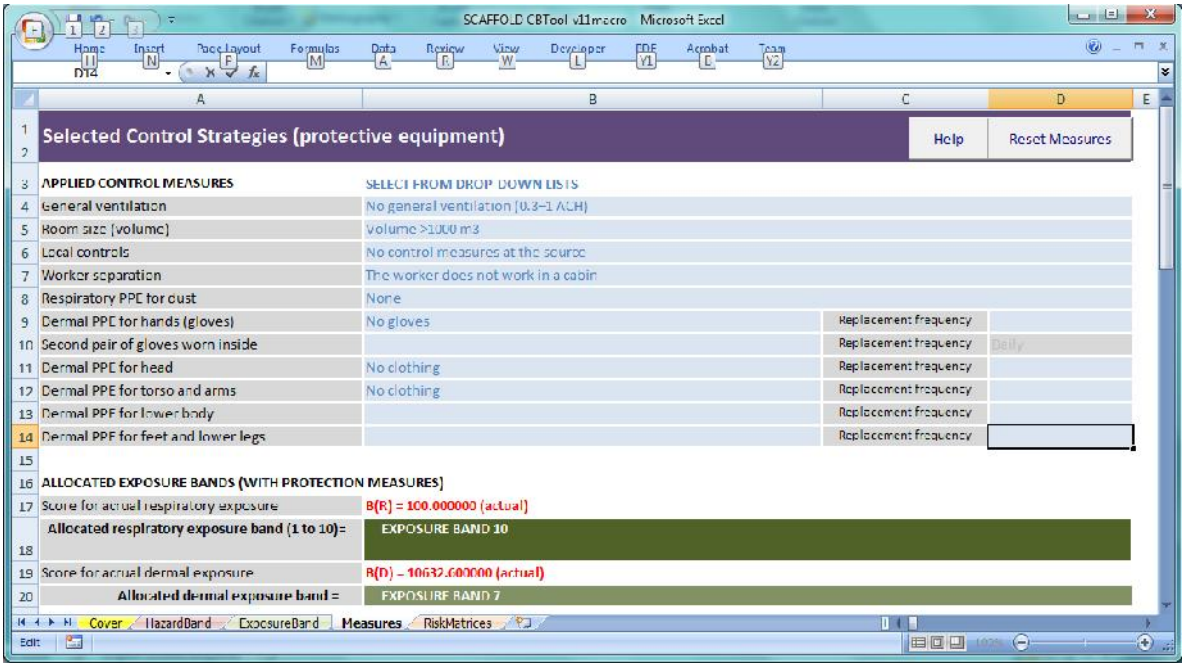

Figure 25 Measures worksheet: Automatic input when the table is reset to the highest actual exposure

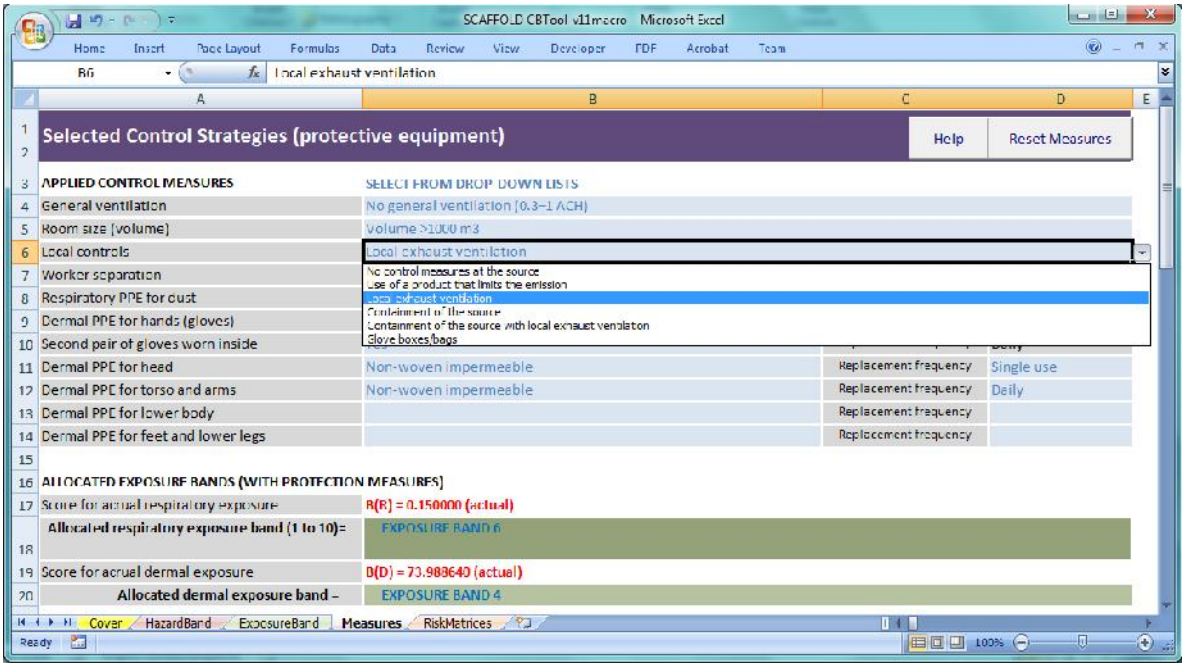

Figure 26 Measures worksheet: Exposure scores (and the bands) are reduced with the use of measures

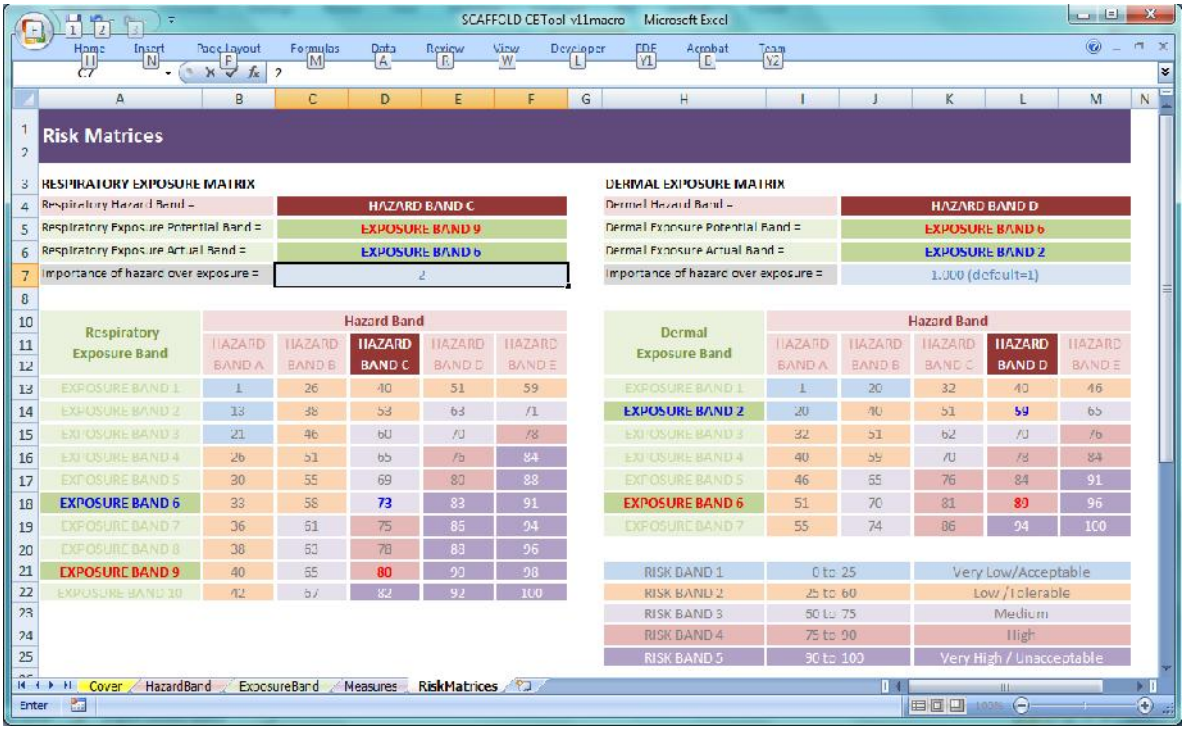

Figure 27 RiskMatrices worksheet: presentation of final results and the 5 risk bands

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