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

APPLICABILITY OF THE DREAM MODEL IN ESTIMATION OF DERMAL EXPOSURE TO MNMs DURING SEVERAL CONSTRUCTION RELATED TASKS – COMPARISON WITH EXPERIMENTAL OBSERVATIONS

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1. EXECUTIVE SUMMARY

In the present study the applicability of already developed dermal-exposure models, which are suitable for general chemicals and biological agents, to manufactured nanomaterials (MNMs) exposure assessment was investigated. In particular, we wanted to find out if any of the existing models are suitable to assess dermal exposure to MNMs during the processes and for the nanomaterials of interest for the SCAFFOLD project.

Literature research showed that up to now there is no dermal exposure model dedicated to nanomaterials in general. On the other hand, some dermal exposure models for general chemicals and/or biological agents were found and investigated for their applicability in the SCAFFOLD project and its purposes. These models are the EASE model, the RISKOFDERM and the DREAM model.

In summary, EASE (Estimation and Assessment of Substance Exposure) is a general model that has been proposed for the prediction of workplace exposure to a wide range of substances hazardous to health for regulatory risk assessments. However, in separate studies it was found that EASE overestimates of actual dermal exposure and, although, it has a number of characteristics that describe exposure, it is still based on many simplifications and does not include a wide range of human and workplace factors. Moreover, the EASE model was not originally developed to take into account dusts and powders.

RISKOFDERM is a dermal exposure model designed to meet the needs of REACH and therefore addresses a large variety of different scenarios. The model exclusively predicts potential exposures. Further, it assumes a cumulative, linear relationship between task duration and dermal loading. However, scenarios that are particularly relevant for metals and metal compounds and are assumed to be associated with the highest level of skin exposure (such as bagging, mixing and unloading) are not addressed in this model.

Finally the DREAM (DeRmal Exposure Assessment Model) is an observational, semi-quantitative method proposed for the assessment of dermal exposures in occupational settings using pre-assigned default values. The outcome is a numerical estimate of exposure levels (categorized into seven levels from zero to extremely high) both on outside clothing layers and uncovered skin (potential dermal exposure) as well as on skin (actual dermal exposure) of workers performing a certain task. DREAM also attempts to provide an insight into the distribution of dermal exposure over the body, and indicates by which routes dermal exposure takes place.

The study of the aforementioned dermal exposure models showed that EASE model is not suitable for the purposes of SCAFFOLD project due to the variety of simplifications that employs, but most importantly because it was not developed for dusts and powders which are very often the state were the MNMs of interest are found in construction industry.

On the other hand, both RISKOFDERM and DREAM seemed to be relevant for SCAFFOLD, although none of them included a nanomaterial specific category. Therefore, these two models was applied in order to estimate the dermal exposure of a worker during spraying a sol-gel containing TiO_2 nanoparticles on a vertical wall. The inputs for RISKOFDERM included information regarding the settings of the task, the distance and position of the worker relative to the contaminant source, the spraying rate and the physical state of the sprayed material (liquid or solid). The model's output is the potential dermal exposure on hands and the rest of the body in mL/min and it is given as a percentile output, i.e. an exposure value below which the estimated exposure will be with a probability equal to the percentile value. As proven by Vaquero Moralejo *et al*. (2014) during SCAFFOLD's experimental pilot study, there was no penetration of nanomaterials through the protective gloves of the personnel, therefore no wipe tests were performed and, consequently, dermal exposure on the hands of the workers was not found quantitatively. Therefore, the output of RISKOFDERM cannot be evaluated in the light of the present project's outputs and, thus, it was decided not to use it further.

The application of the DREAM model in the same exposure scenario (spraying of nano-TiO_2 containing sol-gel), involved the determination of a variety of parameters; from physicochemical characteristics of the material of interest to the description of the task undertaken and the personal protective equipment used by the worker during the task. As a result we obtained both the potential and the actual dermal exposure for the task and their distribution on nine different body parts. The results are given as a (dimensionless) number and the task can be sorted in one of the seven DREAM categories based on either the potential or the actual exposure. The semi-quantitative DREAM was found to be more relevant to the purposes of SCAFFOLD as its results could be, at least qualitatively, compared with the experimental observations of the project's studies.

On this ground, DREAM was used to estimate the potential and actual dermal exposure of workers based on project's deliverable 3.4 that describes the pilot, experimental study of a variety of scenarios for occupational exposure to MNMs, all of which are relevant to tasks and processes performed really in the construction industry. The study of these scenarios with DREAM, showed that the model can give logical/meaningful predictions of the dermal exposure. However, it should be noted that some of the parameters involved in the estimation of the exposure, could be rather subjective and could be based on the intuition/experience of the observer (especially in the total lack of measurements). Therefore, it is possible different observers to draw different conclusions, although between experienced observers the results are not expected to differ greatly.

Overall, with careful application DREAM can be a powerful triage tool; by ranking of tasks and jobs, it helps to prioritize expensive in both efforts and resources experimental measurements by providing information in order to determine who, where, and what to measure. Therefore, it seems to be suitable for the purposes of SCAFFOLD.

2. OBJECTIVES AND SCOPE

Investigation of the applicability of already developed dermal-exposure models, which are suitable for general chemicals and biological agents, to nanomaterial exposure assessment by comparing the dermal exposure estimates of models available in literature with measurements in occupational settings.

3. INTRODUCTION

The goal of the present study is to investigate the applicability of already developed dermal-exposure models, which are suitable for general chemicals and biological agents, to manufactured nanomaterials (MNMs) exposure assessment. More precisely, we are interested to find out if any of the existing models are suitable to estimate dermal exposure to MNMs during the processes and for the nanomaterials relevant to the SCAFFOLD project.

Literature research demonstrates the lack of dermal exposure models dedicated to nanomaterials, in addition to inadequate information regarding dermal exposure to MNMs in general. Conversely, there are some dermal exposure models for general chemicals and/or biological agents, which will be briefly described and their applicability in the SCAFFOLD project and its purposes will be explored. These models are the EASE model, the RISKOFDERM and the DREAM model.

3.1 EASE Model

EASE (Estimation and Assessment of Substance Exposure) is a general model that has been proposed for the prediction of workplace exposure to a wide range of substances hazardous to health for regulatory risk assessments (Cherrie et al., 2003). However, in separate studies it was found that EASE overestimates of actual dermal exposure and, although, it has a number of characteristics that describe exposure, it is still based on many simplifications and does not include a wide range of human and workplace factors (EBRC, 2007). Moreover, the EASE model was not originally developed to take into account dusts and powders (Hughson and Cherrie, 2001) rendering this model unsuitable for the majority of MNMs applications studied in SCAFFOLD project, thus it will be no longer discussed in the present study.

3.2 RISKOFDERM

The RISKOFDERM Dermal Exposure Model is a model for estimating potential dermal exposure, i.e. the total amount of a substance coming into contact with the protective clothing, work clothing and exposed skin. It is based on statistical analysis of data gathered in the RISKOFDERM project, a European project on dermal exposure. The model originally consists of a set of equations as reported in the deliverables of the RISKOFDERM project. These equations have been entered into a user friendly spreadsheet in EXCEL.

Purpose of the model is to estimate potential dermal exposure to a product or substance used for or handled in a separate process or task within a workday and, thus, provides exposure information to regulatory risk assessments of chemical substances.

RISKOFDERM is a dermal exposure model designed to meet the needs of REACH and therefore addresses a large variety of different scenarios:

- Filling, mixing and loading,
- Wiping,
- Dispersion by hand-held tools,

- Spraying,
- Immersion, and
- Mechanical treatment of solid objects.

Depending on the chosen scenario, a variety of other inputs are needed. In addition, the user is asked to provide an output percentile, i.e. the exposure value below which the estimated exposure will be with a probability equal to the percentile value. For example, an output percentile of 75% indicates that there is a probability of 75% that estimated values with the given set of inputs will be below the corresponding exposure value. For details the reader is referred to the literature (TNO, 2006, Van Hemmen et al., 2003).

According to the model's developers (TNO, 2006), the validity of the model has not been established with independent data. The model is based on all relevant data that the researchers could find and few new data have become available since. However, a benchmark study was done after a first draft version of the model was completed. The results of the benchmark study showed that in general the model appeared to be quite reasonable. Nevertheless, it should be noted that the model exclusively predicts potential exposures. Further, it assumes a cumulative, linear relationship between task duration and dermal loading. However, scenarios that are particularly relevant for metals and metal compounds and are assumed to be associated with the highest level of skin exposure (such as bagging, mixing and unloading) are not addressed in this model (EBRC, 2007).

3.3 DREAM

The DeRmal Exposure Assessment Model (DREAM) is an observational, semi-quantitative method proposed for the assessment of dermal exposures in occupational settings using pre-assigned default values (Van Wendel De Joode et al., 2003). The model is based on a conceptual model for dermal exposure assessment, which systematically describes the transport of contaminant mass from exposure sources to the surface of the skin through three main exposure routes: emission, deposition and transfer (Schneider T et al., 1999). The outcome is a numerical estimate of exposure levels (categorized into seven levels from zero to extremely high) both on outside clothing layers and uncovered skin (potential dermal exposure) as well as on skin (actual dermal exposure) of workers performing a certain task. DREAM also attempts to provide an insight into the distribution of dermal exposure over the body, and indicates by which routes dermal exposure takes place.

The accuracy of the DREAM method has been explored by comparing its estimates with quantitative dermal exposure measurements in several occupational settings. The model's developers themselves concluded that the method can be successfully applied for semi-quantitative dermal exposure assessment in epidemiological and occupational hygiene surveys of groups of workers with considerably contrasting dermal exposure levels, whereas for surveys with less contrasting exposure levels, quantitative dermal exposure measurements would be preferable (EBRC, 2007, Van Wendel De Joode et al., 2005a, Van Wendel De Joode et al., 2005b).

3.4 Application to SCAFFOLD

The purpose of this work is to determine, if one or more of the aforementioned models found in literature are appropriate for estimation of dermal exposure in the scenarios relevant to SCAFFOLD, where manufactured nanomaterials are involved. Thus, both RISKOFDERM and DREAM are used next to estimate dermal exposure of a worker, who sprays a vertical wall with a self-cleaning coating containing TiO_2 nanoparticles. The details of this scenario are described by Vaquero Moralejo *et al*. (2014) of the project and in section 5.5 of the present report.

Figure 1. Application of self-cleaning coating on a vertical wall.

In short, the task was performed outdoors and a sol-gel coating was applied on a wall (4 m^2). During the process, one operator was involved who used respirator mask FFP3, gloves and a Tyvek suit. In Figure 1 a picture taken during the task is shown.

3.4.1 RISKOFDERM

In Figure 2, the inputs (top) and the outputs (bottom) of RISKOFDERM are shown. There is no parameter that is related to the fact that there are MNMs in the sprayed material and the use of personal protective equipment by the worker is not taken into account. The output, given in a tabular format, is the hand and body rates of potential dermal exposure in different output percentiles. The model also gives this data in a chart, as shown in Figure 3.

The experimental campaigns performed by Vaquero Moralejo *et al*. (2014) showed that MNMs deposited on the outer surface of the protective gloves, do not penetrate the gloves. Therefore, there was no need for further measurements regarding skin exposure and no quantitative results were obtained. The results of RISKOFDERM cannot be compared with experimental results from the SCAFFOLD, so this model although easy to use is not applicable for the purposes of the project.

1/10/2014 RISKOFDERM potential dermal exposure model vs 2.1t.xls

Inputs	T3.6	Warnings
Where is the spray application done?	Outdoors	
Is spraying done overhead, level or downward?	Overhead	
What is the direction of airflow that comes from the source?	Not clearly away from the worker	
Is the worker segregated from the source?	No	
How far is the source from the worker	Up to 1 meter	
What is the volatility of the carrier liquid?	Not highly volatile	
Is the product sprayed a liquid or a solid?	Liquid	
Application rate of product (L/min or kg/min)	0.05	
Cumulative duration of scenario per shift (min)	20	

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See the guidance for some remarks on different criteria for the performance of the model

Results - percentiles	Hands ($820\ cm^2$)		Body ($18720\ cm^2$)		
	Hands rate (mL/min)	Hands loading (mg)	Body rate (mL/min)	Body loading (mg)	
10.00%	1	19	2	38	
20.00%	2	41	4	83	
30.00%	4	72	7	147	
40.00%	6	117	12	239	
50.00%	9	184	19	376	
60.00%	15	290	30	592	
70.00%	24	471	48	962	
80.00%	42	832	85	1699	
90.00%	92	1830	187	3736	
95.00%	175	3509	358	7164	
99.00%	595	*11900*	1215	24291	May be unrealistic

Spraying_results

Figure 2. RISKOFDERM inputs (top) and outputs (bottom).

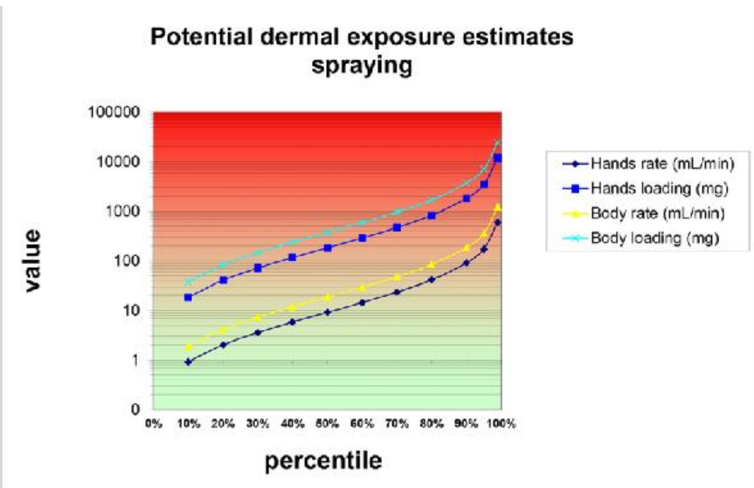

Figure 3. RISKOFDERM – graphical output.

3.4.2 DREAM

Using the DREAM model, total potential dermal exposure is estimated equal to 1323, which sorts the task in the 7th DREAM category (extremely high exposure), whereas if the clothing protection factors are taken into account, the actual dermal exposure is evaluated. The total actual dermal exposure is equal to 16, i.e. corresponds to the 3rd DREAM category of low exposure. This result can be attributed mainly to the personal protection equipment used in this scenario's tasks, which seems to be very effective in this case.

Note: The details of the calculation can be found in section 5.5 of the present work.

Moreover, the partial results for each body part indicate that the actual dermal exposure of hands is almost 6, which corresponds to the 2nd DREAM category of very low exposure. It should be noted that the result is obtained assuming that the protective gloves are partially permeable as suggested by the model. The result with impermeable gloves would be 1.6 that is even closer to the experimentally observed no penetration.

From this example, one can see that the DREAM model gives at least qualitative, results that are meaningful and to some extend comparable to the findings of the project. Therefore, in the next section DREAM will be used to estimate potential and actual dermal exposure for all the occupational exposure scenarios covered in the experimental pilot study by Vaquero Moralejo *et al*. (2014).

4. METHODOLOGY

Herein, the DREAM model will be described briefly. The details for the model development, its evaluation and examples of application can be found in the literature (Van Wendel De Joode et al., 2003, Van Wendel De Joode et al., 2005a, Van Wendel De Joode et al., 2005b).

The dermal exposure within DREAM is evaluated at task level. In fact, both the potential (Skin-$P_{TASK.BP}$) and the actual (Skin-$A_{TASK.BP}$) dermal exposure are estimated. The former refers to the exposure on clothing and bare skin, whereas the latter to eventual skin exposure ("filtered" by the clothing). Potential and actual dermal exposure are calculated for nine different body parts (BPs); head (HE), upper arms (UA), forearms (FA), hands (HA), front torso (FT), back torso (BT), lower body (LB), lower legs (LL) and feet (FE).

The potential dermal exposure for each body part (Skin-$P_{TASK.BP}$) results from the sum of three different routes of exposure; emission (E_{BP}), deposition (D_{BP}) and transfer (T_{BP}):

$$Skin - P_{TASK.BP} = E_{BP} + T_{BP} + D_{BP} \quad . \qquad (1)$$

The exposure estimate for each route (R) on the right hand side of Eq.(1) is the product of the probability ($P_{R.BP}$) and the intensity ($I_{R.BP}$) of the specific route and body part multiplied also by the task's intrinsic emission (E_I) and the weight factor of the route (ER_R):

$$R_{BP} = P_{R.BP} \cdot I_{R.BP} \cdot E_I \cdot ER_R \quad , \qquad (2)$$

where R stands for route and can be E (emission), D (deposition) or T (transfer). The intrinsic emission E_I in Eq.(2), is related to physical and chemical characteristics of the substance of interest. Among others it includes information regarding the concentration of the active ingredient (in our case manufactured nanomaterials, MNMs), its physical state (solid, liquid or vapor) and, in case of solids, formulation (powder/fine particles, granules/pellets/particles or pack/bunch/bundle). Moreover, dermal exposure due to emission has higher weight factor (ER_E=3) than deposition and transfer (ER_D=1 and ER_T=1, respectively), because emission refers to direct exposure from the source, whereas deposition and transfer refer to indirect exposure (or secondary exposure) from airborne ingredients or contaminated surface respectively, where loss is expected.

The actual dermal exposure for each body part is estimated by multiplication of the corresponding potential dermal exposure by the suitable clothing protection factor (O_{BP}). The latter is relevant to the kind of material covering the skin (if any) in the specific body part, the protection factor of this material and the replacement frequency of the clothing. For hand there are additional parameters that contribute to the clothing protection factor for hands (O_{HA}); whether the gloves are appropriately connected to the rest of the clothing, percentage of task duration that the gloves are worn, the use of a second internal pair of gloves and how often it is replaced, and the use of a barrier cream. In general, the actual dermal exposure per body part is given by:

$$Skin - A_{BP} = Skin - P_{BP} \cdot O_{BP} \quad . \qquad (3)$$

Finally, the total potential (Skin-P_{TASK}) and actual (Skin-A_{TASK}) per task is also estimated as the sum of the respective exposure for all body parts weighted on each BP's body surface factor (BS_{BP}), which is the surface area of an individual body part divided by the mean surface area of the nine body parts and is shown in Table 1:

$$Skin-P_{TASK} = \sum_{BP=1}^{9} \left(Skin-P_{BP} \cdot BS_{BP} \right) , \tag{4}$$

and

$$Skin-A_{TASK} = \sum_{BP=1}^{9} \left(Skin-A_{BP} \cdot BS_{BP} \right) . \tag{5}$$

Table 1. Body Surface Factor (BS_{BP}) (Van Wendel De Joode et al., 2003).

Body Part	Body Surface Factor	Body Part	Body Surface Factor
Head	0.69	**Torso Back**	1.22
Upper Arms	0.67	**Lower Body**	2.43
Forearms	0.53	**Lower Legs**	1.15
Hands	0.47	**Feet**	0.63
Torso Front	1.22		

Based on the results of Eqs.(4) and (5), the task can be sorted into one of the seven DREAM categories for dermal exposure; 1. 0 = no exposure, 2. 0-10 = very low, 3. 10-30 = low, 4. 30-100 = moderate, 5. 100-300 = high, 6. 300-1000 = very high, and 7. >1000 = extremely high.

In summary the model is shown in Figure 4.

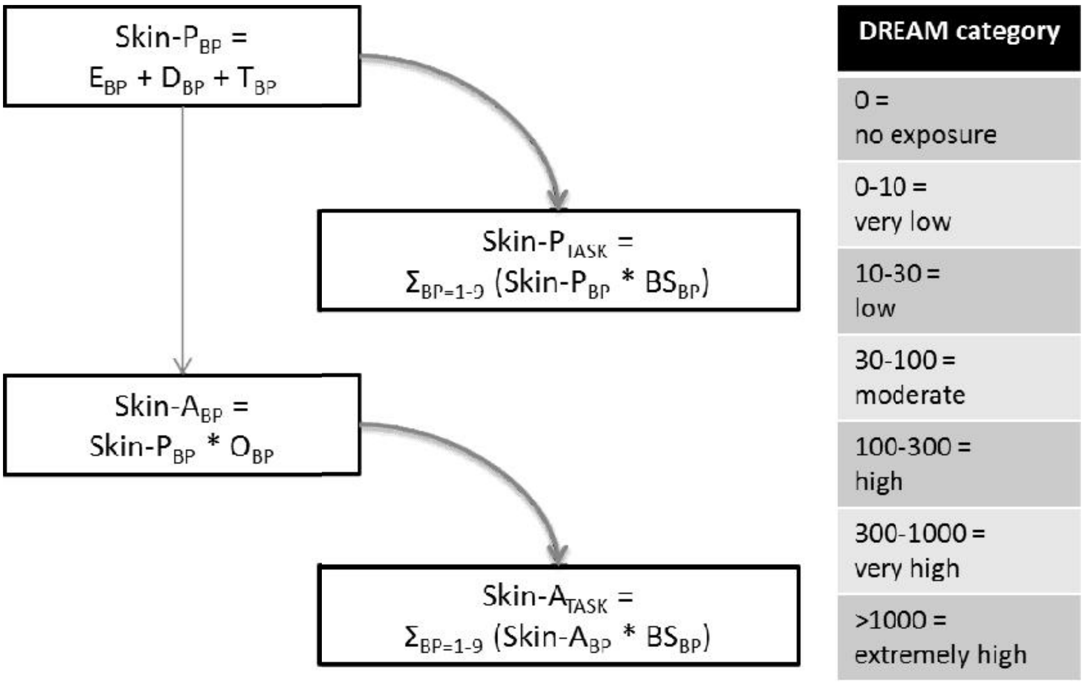

Figure 4. Summary of the dermal exposure assessment model (DREAM). Adapted from Van Wendel De Joode et al. (2003).

5. RESULTS & DISCUSSION

In this chapter the dermal exposure assessment model (DREAM) of Van Wendel De Joode et al. (2003) is used to estimate dermal exposure to manufactured nanomaterials (MNMs) or other substances that contain MNMs during a variety of occupational exposure scenarios.

In particular, DREAM is applied for the eight occupational exposure scenarios performed in pilot-scale for the purposes of the SCAFFOLD project (Table 2). A full description of the scenarios and the pilot study findings anew is beyond the purpose of the present report and unnecessary as the scenarios are described in detail by Vaquero Moralejo (2014). Thus here only information relevant to dermal exposure assessment will be repeated.

Table 2. Short description of occupational exposure scenarios performed in the pilot study (Vaquero Moralejo, 2014).

Scenario	Description
1	nano TiO_2 manufacturing process (1short)
2	nano TiO_2 manufacturing process (2long)
3	Depollutant mortar manufacturing process (containing nano-TiO_2)
4	Depollutant mortar application (containing nano-TiO_2)
5	Demolition of cabins covered with nano-TiO_2 and nano-SiO_2
6	Self-cleaning coatings application (containing nano-TiO2)
7	Machining of samples (drilling): - depollutant mortar (nano-TiO_2) - self-compacting concrete (nano-SiO_2) - self-cleaning coating (nano-TiO_2) - FR panels (nanoclays)
8	Machining of samples (sawing) of CNF coatings

5.1 Nano-TiO_2 Manufacturing Process

This scenario corresponds to the manufacturing process of TiO_2 nano-powders. This process was monitored twice; one in February (21 February 2013) (short) and the other one in July (4-5 July2013) (long). The first one was a preliminary test and the duration of the tasks were shortened (compared to normal operation) to have an overview of the processes. Second measurement was performed during two days in normal operation.

As the duration of the processes are irrelevant for the determination of the DREAM category and due to the fact that scenarios 1 and 2 of the pilot study comprise of the same tasks, in the present study these two scenarios are treated as one for the estimation of the dermal exposure.

5.1.1 Short description

Nano-TiO2 manufacturing process was measured in an industrial site (TECNAN). The nano-TiO_2 produced is in 15 nm size (primary particles). The production is performed in an industrial warehouse with a surface of approx. 1250 m^2 and has both natural and automatic ventilation. The whole process consists of five different tasks;

Task 1 (T1): Reaction

Raw materials are introduced into the reaction chamber where the synthesis process takes place. During the reaction the machine is closed and the hose filters are beaten every 17 seconds automatically.

Task 2 (T2): Beating

When the reaction is finished, the hose filters are beaten during several hours. This task is done in order to collect all the nano-powder produced and collected on the filters. After the beating process there is a period for powder settlement before the final product is collected.

Task 3 (T3): Final product collection

The collection of the final product is done opening a hatch located behind the reaction chamber.

Task 4 (T4): Cleaning

In this task, the hoper filters, pipes and reactor chamber are cleaned. The cleaning of the hoper filters includes their disassembly and cleaning one by one with a water-vacuum cleaner. After cleaning the filters, they are introduced in individual containers for storage. Reactor chamber and pipes are also cleaned with the same vacuum cleaner.

Task 5 (T5): Product transferring

After the collection, the produced powder is transferred to small containers of 100gr each. This task is performed inside a fume hood devoted to this task.

In this case, DREAM is applied for Tasks 3 through 5, because Tasks 1 and 2 are performed inside the closed production machine and it is assumed that there is no accidental release during these tasks. T3 and T4, where the personnel involved is fully exposed to the MNMs, are treated in the same manner in DREAM, whereas for T5 a different calculation is needed as the task is performed inside a fume hood.

Table 3. Clothing factors for the different body parts: Nano-TiO_2 Manufacturing Process (T3, T4 and T5).

Variable	Name	Formula	Value	
Clothing factor hands	O_{HA}	O_{HA}=M*PFM_{HA}*RF*GC*UG*URF*BC	O_{HA}= 0.1*1*0.3* 1*1*0.3 *1*1=	0.009
Clothing factor other body parts	O_{BP}	O_{BP}=M*PFM_{BP}*RF	O_{HE}=0.1*0.3*0.3=	0.009
			O_{UA}=0.1*0.3*0.3=	0.009
			O_{FA}=0.1*0.3*0.3=	0.009
			O_{TF}=0.1*0.3*0.3=	0.009
			O_{TB}=0.1*0.3*0.3=	0.009
			O_{LB}=0.1*0.3*0.3=	0.009
			O_{LL}=0.1*0.3*0.3=	0.009
			O_{FE}=0.03*0.3*10=	0.09

During T3, T4 and T5 (collection, cleaning and transferring) the operators used full face masks, gloves (2 pairs) and Tyvek coveralls. The clothing protection factors for each body part that hold for all three tasks are shown in Table 3.

5.1.2 Potential exposure – T3 (collection) & T4 (cleaning)

Table 4. Potential skin exposure: Nano-TiO_2 Manufacturing Process – Collection (T3) & Cleaning (T4).

Variable	Name	Formula	Value	
Intrinsic emission	**E_I**	**E_I= PS*C*F*DU*SS**	**E_I=1*1*3*3*1=**	**9**
Emission to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	E_{BP}	E_{BP}=ER_E*$P_{E.BP}$*$I_{E.BP}$*E_I	E_{HE}=3*10*10*9=	2700
			E_{UA}=3*10*10*9=	2700
			E_{FA}=3*10*10*9=	2700
			E_{HA}=3*10*10*9=	2700
			E_{TF}=3*10*10*9=	2700
			E_{TB}= 3*0*0*9=	0
			E_{LB}= 3*3*3*9=	243
			E_{LL}= 3*1*1*9=	27
			E_{FE}= 3*1*1*9=	27
Total emission	**E_{TOT}**	**E_{TOT} = $\Sigma_{BP=1-9}E_{BP}$**	**E_{TOT}=**	**13797**
Deposition on head, upper arms, forearms, hands, torso front, torsoback, lower body part, lower legs, feet	D_{BP}	D_{BP}=ER_D*$P_{D.BP}$*$I_{D.BP}$*Dp_{BP}*E_I	D_{HE}=1*10*10*1*9=	900
			D_{UA}=1*10*10*1*9=	900
			D_{FA}=1*10*10*1*9=	900
			D_{HA}=1*10*10*1*9=	900
			D_{TF}=1*10*10*1*9=	900
			D_{TB}=1*3*3*1*9=	27
			D_{LB}=1*3*3*1*9=	81
			D_{LL}=1*3*3*1*9=	81
			D_{FE}=1*3*3*1*9=	81
Total deposition	**D_{TOT}**	**D_{TOT} = $\Sigma_{BP=1-9}D_{BP}$**	**D_{TOT}=**	**4770**
Transfer to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	T_{BP}	T_{BP}=ER_T*$P_{T.BP}$*$I_{T.BP}$*Tr_{BP}*E_I	T_{HE}=1*0*3*0*9=	0
			T_{UA}=1*0*3*0*9=	0
			T_{FA}=1*10*3*1*9=	900
			T_{HA}=1*10*3*1*9=	900
			T_{TF}=1*10*3*1*9=	900
			T_{TB}=1*0*3*0*9=	0
			T_{LB}=1*0*3*0*9=	0
			T_{LL}=1*0*3*0*9=	0
			T_{FE}=1*1*3*1*9=	27
Total transfer	**T_{TOT}**	**T_{TOT} = $\Sigma_{BP=1-9}T_{BP}$**	**T_{TOT}=**	**2727**
Potential skin exposure per body part	Skin-P_{BP}	Skin-P_{BP}=E_{BP}+D_{BP}+T_{BP}	Skin-P_{HE}=	3600
			Skin-P_{UA}=	3600
			Skin-P_{FA}=	4500
			Skin-P_{HA}=	4500
			Skin-P_{TF}=	4500
			Skin-P_{TB}=	27
			Skin-P_{LB}=	324
			Skin-P_{LL}=	108
			Skin-P_{FE}=	135
Total potential skin exposure	**Skin-P_{TASK}**	**Skin-P_{TASK}=$\Sigma_{BP=1-9}$(Skin-P_{BP}*BS_{BP})**	**Skin-P_{TASK}=**	**15915.51**

In

Table 4 the detailed calculation of the potential dermal exposure during each of the tasks of collection and cleaning is shown. The nature of the tasks indicates that apart from direct exposure from the particles source (i.e. emission), deposition will also be significant in this case because of the active ingredient (that is the MNMs of 15nm size) are very small and we presume that the dustiness is high also. The total potential dermal exposure is almost 16000 that sorts T3 and T4 in the 7th DREAM category of extremely high dermal exposure (see also Figure 4).

5.1.3 Actual exposure – T3 (collection) & T4 (cleaning)

Taking into account the clothing protection factors of Table 3, the actual dermal exposure can be evaluated. The results are shown in Table 5 for each body part and for the whole task. The total actual dermal exposure is equal to 150, i.e. corresponds to the 5th DREAM category (high exposure).

Table 5. Actual skin exposure: Nano-TiO_2 Manufacturing Process – Collection (T3) & Cleaning (T4).

Variable	Name	Formula	Value	
Actual skin exposure for each body part	Skin-A_{BP}	Skin-A_{BP}=Skin-P_{BP}*O_{BP}*BS_{BP}	Skin-A_{HE}=	32.4
			Skin-A_{UA}=	32.4
			Skin-A_{FA}=	40.5
			Skin-A_{HA}=	40.5
			Skin-A_{TF}=	40.5
			Skin-A_{TB}=	0.243
			Skin-A_{LB}=	2.916
			Skin-A_{LL}=	0.972
			Skin-A_{FE}=	12.15
Total actual skin exposure	**Skin-A_{TASK}**	**Skin-A_{TASK}=$\Sigma_{BP=1-9}$(Skin-A_{BP}*BS_{BP})**	**Skin-A_{TASK}=**	**150.13**

5.1.4 Potential exposure – T5 (transferring)

In Table 6 the detailed calculation of the potential dermal exposure during the task of transferring is shown. The nature of the task, i.e. performed under a fume hood, indicates that only the hands will be affected during the task. Moreover, emission is thought to be the most significant exposure route, whereas the intensity of both deposition and transfer is assumed medium for the very small MNMs (15nm) and the high dustiness (they will disperse in air very quickly). The total potential dermal exposure is 1438 that sorts T5 in the 7th DREAM category of extremely high dermal exposure (see also Figure 4).

5.1.5 Actual exposure – T5 (transferring)

Taking into account the clothing protection factors of Table 3, the actual dermal exposure can be evaluated. The results are shown in Table 7 for each body part and for the whole T5. The total actual dermal exposure is equal to 13, i.e. corresponds to the 3th DREAM category of low exposure.

Table 6. Potential skin exposure: Nano-TiO_2 Manufacturing Process – Transferring (T5).

Variable	Name	Formula	Value	
Intrinsic emission	**E_I**	**E_I= PS*C*F*DU*SS**	**E_I=1*1*3*3*1=**	**9**
Emission to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	E_{BP}	E_{BP}=ER_E*$P_{E.BP}$*$I_{E.BP}$*E_I	E_{HE}=3*0*10*9=	0
			E_{UA}=3*0*10*9=	0
			E_{FA}=3*0*10*9=	0
			E_{HA}=3*10*10*9=	2700
			E_{TF}=3*0*10*9=	0
			E_{TB}= 3*0*0*9=	0
			E_{LB}= 3*0*3*9=	0
			E_{LL}= 3*0*1*9=	0
			E_{FE}= 3*0*1*9=	0
Total emission	**E_{TOT}**	**$E_{TOT} = \Sigma_{BP=1-9} E_{BP}$**	**E_{TOT}=**	**2700**
Deposition on head, upper arms, forearms, hands, torso front, torsoback, lower body part, lower legs, feet	D_{BP}	D_{BP}=ER_D*$P_{D.BP}$*$I_{D.BP}$*Dp_{BP}*E_I	D_{HE}=1*0*10*0*9=	0
			D_{UA}=1*0*10*0*9=	0
			D_{FA}=1*0*1*0*9=	0
			D_{HA}=1*10*3*9=	270
			D_{TF}=1*0*10*0*9=	0
			D_{TB}=1*0*3*0*9=	0
			D_{LB}=1*0*3*0*9=	0
			D_{LL}=1*0*3*0*9=	0
			D_{FE}=1*0*3*0*9=	0
Total deposition	**D_{TOT}**	**$D_{TOT} = \Sigma_{BP=1-9} D_{BP}$**	**D_{TOT}=**	**270**
Transfer to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	T_{BP}	T_{BP}=ER_T*$P_{T.BP}$*$I_{T.BP}$*Tr_{BP}*E_I	T_{HE}=1*0*3*0*9=	0
			T_{UA}=1*0*3*0*9=	0
			T_{FA}=1*0*3*0*9=	0
			T_{HA}=1*10*1*1*9=	90
			T_{TF}=1*0*3*0*9=	0
			T_{TB}=1*0*3*0*9=	0
			T_{LB}=1*0*3*0*9=	0
			T_{LL}=1*0*3*0*9=	0
			T_{FE}=1*0*3*0*9=	0
Total transfer	**T_{TOT}**	**$T_{TOT} = \Sigma_{BP=1-9} T_{BP}$**	**T_{TOT}=**	**90**
Potential skin exposure per body part	Skin-P_{BP}	Skin-P_{BP}=E_{BP}+D_{BP}+T_{BP}	Skin-P_{HE}=	0
			Skin-P_{UA}=	0
			Skin-P_{FA}=	0
			Skin-P_{HA}=	3060
			Skin-P_{TF}=	0
			Skin-P_{TB}=	0
			Skin-P_{LB}=	0
			Skin-P_{LL}=	0
			Skin-P_{FE}=	0
Total potential skin exposure	**Skin-P_{TASK}**	**Skin-P_{TASK}=$\Sigma_{BP=1-9}$(Skin-P_{BP}*BS_{BP})**	**Skin-P_{TASK}=**	**1438.2**

Table 7. Actual skin exposure: Nano-TiO_2 Manufacturing Process – Transferring (T5).

Variable	Name	Formula	Value	
Actual skin exposure for each body part	$Skin\text{-}A_{BP}$	$Skin\text{-}A_{BP}=Skin\text{-}P_{BP}*O_{BP}*BS_{BP}$	$Skin\text{-}A_{HE}$=	0
			$Skin\text{-}A_{UA}$=	0
			$Skin\text{-}A_{FA}$=	0
			$Skin\text{-}A_{HA}$=	27.54
			$Skin\text{-}A_{TF}$=	0
			$Skin\text{-}A_{TB}$=	0
			$Skin\text{-}A_{LB}$=	0
			$Skin\text{-}A_{LL}$=	0
			$Skin\text{-}A_{FE}$=	0
Total actual skin exposure	$Skin\text{-}A_{TASK}$	$Skin\text{-}A_{TASK}=\Sigma_{BP=1\text{-}9}(Skin\text{-}A_{BP}*BS_{BP})$	$Skin\text{-}A_{TASK}$=	**12.94**

5.2 Depollutant Mortar Manufacturing Process (containing nano-TiO_2)

This scenario relates to the manufacturing of depollutant mortar (TiO_2). This scenario was monitored the 28 May 2013 in a mortar manufacturer industry provided by ACCIONA.

5.2.1 Short description

Three formulations of depollutant mortar were manufactured (1 Tn for each material): mortar control (A); mortar (B) filled with TiO_2 supported on sepiolite (this product was developed by Tolsa-Acciona and its composition is 50% sepiolite and 50% nano-TiO_2); and mortar (C) filled with nanoTiO2 (aeroxide). The additive added in Material B, TiO_2-sepiolite, has been developed by TOLSA-ACCIONA to achieve better TiO_2 dispersions and following the "safe by design" concept (nanoTiO_2 fixed on sepiolite). Its composition is 50% nano-TiO_2 and 50% sepiolite (weight). Batch size was 1 Ton so the quantities added of nano-TiO_2 to Materials B and C is the same, 4.1 kg. The nano-TiO2 added in Material C is commercial Aeroxide P25, from Evonix.

Figure 5. Snapshots of T1 (left), T2 (middle) and T3 (right).

The process includes three tasks; T1: additive weighing, T2: additive adding to the hopper and T3: mortar bagging. Pictures taken during the process are shown in Figure 5.

Task 1 (T1): Weighing additives; This task was performed in a weighing area. Only standard additives (3,7kg) were weighted for Material A, Standard additives (3,7kg) and TiO_2-sepiollite (8,2kg) for Material B and standard additives (3,7kg) and nano-TiO_2 (4,1kg) for Material C. The rest of the components were added and weighted automatically.

Task 2 (T2): Adding additives to the hopper ; After automatic adding of the mortar and the sand (from external hoppers) in the mixer, the worker added manually the rest of the additives to the hopper. In the case of the Material A, standard additives (3,7kg) are added; for Material B, standard additives (3,7kg) and TiO_2-sepiollite (8,2kg) are added; finally for Material C., standard additives (3,7kg) and TiO_2 (4,1kg) was added to the mixer. The mixer was ON during this task.

Task 3 (T3): Bagging final product ; In the bagging task, the mortar is filled in bags, semi automatically (25Kg each bag).

This scenario was performed in an industrial site of 1250 m^2. The industrial warehouse has natural ventilation and the bagging machine has additional LEV at both sides of the bagging point.

As seen from Figure 5, all three tasks involve similar exposure patterns for the personnel. Thus one DREAM calculation will be performed for all scenarios.

During the process, the worker used a respirator mask FFP3 and gloves. In

Table 8 clothing protection factors for each body part that hold for all three tasks are shown.

Table 8. Clothing factors for the different body parts: Depollutant Mortar Manufacturing Process.

Variable	Name	Formula	Value	
Clothing factor hands	O_{HA}	O_{HA}=M*PFM_{HA}*RF*GC*UG*URF*BC	O_{HA}= 0.1*1*1*1*1*1 *1*1=	0.1
Clothing factor other body parts	O_{BP}	O_{BP}=M*PFM_{BP}*RF	O_{HE}=no protection	1
			O_{UA}=0.3*0.3*1=	0.09
			O_{FA}=0.3*0.3*1=	0.09
			O_{TF}=0.3*0.3*1=	0.09
			O_{TB}=0.3*0.3*1=	0.09
			O_{LB}=0.3*0.3*1=	0.09
			O_{LL}=0.3*0.3*1=	0.09
			O_{FE}=0.03*0.3*10=	0.09

5.2.2 Potential exposure

The details of potential dermal exposure estimation are shown in Table 9. We assume that the main contribution to dermal exposure is from emission , following by deposition (due to small MNMs size and high dustiness) and lower transfer (the worker handles the material but not so much the equipment). The total potential dermal exposure of 1414 sorts these tasks in the 7th DREAM category (extremely high exposure).

5.2.3 Actual exposure

Taking into account the clothing protection factors of Table 8, the actual dermal exposure is evaluated. The results are shown in Table 10 for each body part and each task of this scenario. The total actual dermal exposure is equal to 355, i.e. corresponds to the 6th DREAM category of high exposure. This high exposure category is attributed mainly to the poor personal protection equipment used in this scenario's tasks. In fact, the highest contribution to the total exposure comes from the head which is not covered in this case. Moreover, the fact that the worker wears regular-casual clothing instead of protective cover-up contributes as well to the high estimated exposure.

Table 9. Potential skin exposure: Depollutant Mortar Manufacturing Process.

Variable	Name	Formula	Value	
Intrinsic emission	**E_I**	**E_I=PS*C*F*DU*SS**	**E_I=1*0.1*3*3*1=**	**0.9**
Emission to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	E_{BP}	$E_{BP}=ER_E*P_{E.BP}*I_{E.BP}*E_I$	E_{HE}=3*10*10*0.9=	270
			E_{UA}=3*10*10*0.9=	270
			E_{FA}=3*10*10*0.9=	270
			E_{HA}=3*10*10*0.9=	270
			E_{TF}=3*10*10*0.9=	270
			E_{TB}= 3*0*0*0.9=	0
			E_{LB}= 3*3*3*0.9=	24.3
			E_{LL}= 3*1*1*0.9=	2.7
			E_{FE}= 3*1*1*0.9=	2.7
Total emission	**E_{TOT}**	**$E_{TOT}=\Sigma_{BP=1-9}E_{BP}$**	**E_{TOT}=**	**1379.7**
Deposition on head, upper arms, forearms, hands, torso front, torsoback, lower body part, lower legs, feet	D_{BP}	$D_{BP}=ER_D*P_{D.BP}*I_{D.BP}*Dp_{BP}*E_I$	D_{HE}=1*10*10*1*0.9=	90
			D_{UA}=1*10*10*1*0.9=	90
			D_{FA}=1*10*10*1*0.9=	90
			D_{HA}=1*10*10*1*0.9=	90
			D_{TF}=1*10*10*1*0.9=	90
			D_{TB}=1*3*1*1*0.9=	2.7
			D_{LB}=1*3*3*1*0.9=	8.1
			D_{LL}=1*3*3*1*0.9=	8.1
			D_{FE}=1*3*3*1*0.9=	8.1
Total deposition	**D_{TOT}**	**$D_{TOT}=\Sigma_{BP=1-9}D_{BP}$**	**D_{TOT}=**	**477**
Transfer to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	T_{BP}	$T_{BP}=ER_T*P_{T.BP}*I_{T.BP}*Tr_{BP}*E_I$	T_{HE}=1*0*3*0*0.9=	0
			T_{UA}=1*0*3*0*0.9=	0
			T_{FA}=1*1*3*1*0.9=	2.7
			T_{HA}=1*10*3*1*0.9=	27
			T_{TF}=1*3*3*1*0.9=	8.1
			T_{TB}=1*0*3*0*0.9=	0
			T_{LB}=1*0*3*0*0.9=	0
			T_{LL}=1*0*3*1*0.9=	0
			T_{FE}=1*0*3*1*0.9=	0
Total transfer	**T_{TOT}**	**$T_{TOT}=\Sigma_{BP=1-9}T_{BP}$**	**T_{TOT}=**	**37.8**
Potential skin exposure per body part	Skin-P_{BP}	Skin-$P_{BP}=E_{BP}+D_{BP}+T_{BP}$	Skin-P_{HE}=	360
			Skin-P_{UA}=	360
			Skin-P_{FA}=	362.7
			Skin-P_{HA}=	387
			Skin-P_{TF}=	368.1
			Skin-P_{TB}=	2.7
			Skin-P_{LB}=	32.4
			Skin-P_{LL}=	10.8
			Skin-P_{FE}=	10.8
Total potential skin exposure	**Skin-P_{TASK}**	**Skin-$P_{TASK}=\Sigma_{BP=1-9}$(Skin-$P_{BP}*BS_{BP}$)**	**Skin-P_{TASK}=**	**1414.1**

Table 10. Actual skin exposure: Depollutant Mortar Manufacturing Process.

Variable	Name	Formula	Value	
Actual skin exposure for each body part	$Skin\text{-}A_{BP}$	$Skin\text{-}A_{BP}=Skin\text{-}P_{BP}*O_{BP}*BS_{BP}$	$Skin\text{-}A_{HE}=$	360
			$Skin\text{-}A_{UA}=$	32.4
			$Skin\text{-}A_{FA}=$	32.643
			$Skin\text{-}A_{HA}=$	38.7
			$Skin\text{-}A_{TF}=$	33.129
			$Skin\text{-}A_{TB}=$	0.243
			$Skin\text{-}A_{LB}=$	2.916
			$Skin\text{-}A_{LL}=$	0.972
			$Skin\text{-}A_{FE}=$	0.972
Total actual skin exposure	$\mathbf{Skin\text{-}A_{TASK}}$	$\mathbf{Skin\text{-}A_{TASK}=\Sigma_{BP=1\text{-}9}(Skin\text{-}A_{BP}*BS_{BP})}$	$\mathbf{Skin\text{-}A_{TASK}=}$	**355.13**

5.3 Depollutant Mortar Application (containing nano-TiO_2)

This scenario relates to the application of depollutant mortar (TiO_2) in a wall. This scenario was monitored the 29 May 2013 in a manufacturer industry provided by ACCIONA.

5.3.1 Short description

The depollutant mortar is applied in a wall, outdoors. Three materials were applied sequentially: Material A (mortar control); Material B (mortar doped with TiO_2 supported on sepiolite: this product was developed by Tolsa-Acciona and its composition is 50% sepiolite and 50% nano-TiO2); and Material C (mortar doped with nano-TiO_2, aeroxide) in a wall (8 m^2) which was divided in three equal parts (each material was applied to each part). The additive added in Material B, TiO_2-sepiolite, has been developed by TOLSA-ACCIONA. Its composition is 50% nano-TiO_2 and 50% sepiolite (weight). The nano-TiO_2 added in Material C is commercial Aeroxide P25, from Evonix.

Figure 6. Snapshots of the process; Mixing (left), Application (middle) and Scrapping (right).

This process includes three different tasks;

- Task 1 (T1) and Task 2 (T2): Mortar mixing and application; the mortar (powder) was added into a bin containing water. Then, the mortar was mixed using a mortar standard mixer (HILTI model). The mortar was then applied on the wall until the mixture was finished. The two first tasks were repeated until the wall was all covered.
- Task 3 (T3): Scraping ; 4 hours later, the mortar was scrapped using conventional handle scrapping tools. When this task is performed the mortar in the wall is partially set, so yet some wet is remaining and the material is not totally dry.

In Figure 6 some pictures of the process are shown. As already mentioned, this scenario is performed outside.

During the process, the worker used a respirator mask FFP3 and gloves. The corresponding clothing protection factors for all three tasks are show in Table 11.

Table 11. Clothing factors for the different body parts: Depollutant Mortar Application.

Variable	Name	Formula	Value	
Clothing factor hands	O_{HA}	O_{HA}=M*PFM_{HA}*RF*GC*UG*URF*BC	O_{HA}= 0.1*1*0.3*1*1*1 *1*1=	0.03
Clothing factor other body part	O_{BP}	O_{BP}=M*PFM_{BP}*RF	O_{HE}=no protection	1
			O_{UA}=0.3*0.3*0.3=	0.027
			O_{FA}=0.3*0.3*0.3=	0.027
			O_{TF}=0.3*0.3*0.3=	0.027
			O_{TB}=0.3*0.3*0.3=	0.027
			O_{LB}=0.3*0.3*0.3=	0.027
			O_{LL}=0.3*0.3*0.3=	0.027
			O_{FE}=0.03*0.3*10=	0.09

The tasks that constitute this scenario cannot be handled as one from DREAM, as different conditions hold for each one. The estimation of potential and actual dermal exposure for each task is described next.

5.3.2 Potential exposure: Task 1 – Mortar Mixing

In this task, we assume that the main exposure will be due to the dry ingredient added, which also contains the MNMs, to water and before this is fully incorporated to the liquid during mixing. Therefore the intrinsic emission is calculated for solid with fine particles and high dustiness. Moreover, the mixing is done while the worker stands by the container of the mixture (Figure 6 – left), thus the lower body parts are most affected.

The details of potential dermal exposure estimation are shown in Table 12. The total potential dermal exposure of 307 marginally sorts these tasks in the 6th DREAM category of high exposure. Highest exposure occurs on the lower legs and the feet.

5.3.3 Actual exposure: Task 1 – Mortar Mixing

Taking into account the clothing protection factors of Table 11, the actual dermal exposure is evaluated. The results are shown in Table 13 for each body part and each task of this scenario. The total actual dermal exposure is equal to 13, i.e. corresponds to the 3rd DREAM category of low exposure.

Table 12. Potential skin exposure: Depollutant Mortar Application Process – Task 1. Mortar Mixing.

Variable	Name	Formula	Value	
Intrinsic emission	E_I	E_I=PS*C*F*DU*SS	E_I=1*0.1*3*3*1=	**0.9**
Emission to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	E_{BP}	$E_{BP}=ER_E*P_{E.BP}*I_{E.BP}*E_I$	E_{HE}=3*0*1*0.9=	0
			E_{UA}=3*0*1*0.9=	0
			E_{FA}=3*0*1*0.9=	0
			E_{HA}=3*1*1*0.9=	2.7
			E_{TF}=3*1*1*0.9=	2.7
			E_{TB}= 3*0*0*0.9=	0
			E_{LB}= 3*3*3*0.9=	24.3
			E_{LL}= 3*10*3*0.9=	81
			E_{FE}= 3*10*3*0.9=	81
Total emission	E_{TOT}	$E_{TOT}=\Sigma_{BP=1\text{-}9}E_{BP}$	E_{TOT}=	**191.7**
Deposition on head, upper arms, forearms, hands, torso front, torsoback, lower body part, lower legs, feet	D_{BP}	$D_{BP}=ER_D*P_{D.BP}*I_{D.BP}*Dp_{BP}*E_I$	D_{HE}=1*0*1*0*0.9=	0
			D_{UA}=1*0*1*0*0.9=	0
			D_{FA}=1*0*1*0*0.9=	0
			D_{HA}=1*1*3*1*0.9=	2.7
			D_{TF}=1*1*3*1*0.9=	2.7
			D_{TB}=1*0*0*0*0.9=	0
			D_{LB}=1*3*3*1*0.9=	8.1
			D_{LL}=1*10*3*1*0.9=	27
			D_{FE}=1*10*3*1*0.9=	27
Total deposition	D_{TOT}	$D_{TOT}=\Sigma_{BP=1\text{-}9}D_{BP}$	D_{TOT}=	**67.5**
Transfer to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	T_{BP}	$T_{BP}=ER_T*P_{T.BP}*I_{T.BP}*Tr_{BP}*E_I$	T_{HE}=1*0*3*0*0.9=	0
			T_{UA}=1*0*3*0*0.9=	0
			T_{FA}=1*0*3*0*0.9=	0
			T_{HA}=1*10*3*1*0.9=	27
			T_{TF}=1*0*3*0*0.9=	0
			T_{TB}=1*0*3*0*0.9=	0
			T_{LB}=1*0*3*0*0.9=	0
			T_{LL}=1*3*3*1*0.9=	8.1
			T_{FE}=1*3*3*1*0.9=	8.1
Total transfer	T_{TOT}	$T_{TOT}=\Sigma_{BP=1\text{-}9}T_{BP}$	T_{TOT}=	**43.2**
Potential skin exposure per body part	Skin-P_{BP}	Skin-$P_{BP}=E_{BP}+D_{BP}+T_{BP}$	Skin-P_{HE}=	0
			Skin-P_{UA}=	0
			Skin-P_{FA}=	0
			Skin-P_{HA}=	32.4
			Skin-P_{TF}=	5.4
			Skin-P_{TB}=	0
			Skin-P_{LB}=	32.4
			Skin-P_{LL}=	116.1
			Skin-P_{FE}=	116.1
Total potential skin exposure	**Skin-P_{TASK}**	**Skin-P_{TASK}= $\Sigma_{BP=1\text{-}9}$(Skin-$P_{BP}*BS_{BP}$)**	**Skin-P_{TASK}=**	**307.21**

Table 13. Actual skin exposure: Depollutant Mortar Application Process – Task 1. Mortar Mixing.

Variable	Name	Formula	Value	
Actual skin exposure for each body part	Skin-A_{BP}	Skin-A_{BP}=Skin-P_{BP}*O_{BP}*BS_{BP}	Skin-A_{HE}=	0
			Skin-A_{UA}=	0
			Skin-A_{FA}=	0
			Skin-A_{HA}=	0.972
			Skin-A_{TF}=	0.1458
			Skin-A_{TB}=	0
			Skin-A_{LB}=	0.8748
			Skin-A_{LL}=	3.1347
			Skin-A_{FE}=	10.449
Total actual skin exposure	**Skin-A_{TASK}**	**Skin-A_{TASK}=$\Sigma_{BP=1-9}$(Skin-A_{BP}*BS_{BP})**	**Skin-A_{TASK}=**	**12.948**

5.3.4 Potential exposure: Task 2 – Mortar Application

This task involves the application of the mortar, which is a paste-like liquid (i.e. high viscosity), on a vertical wall. Emission is assumed to be the dominant exposure route, deposition will be low for such a material and transfer can be only achieved on the hands by the brush the worker uses. Moreover, in this case the worker is more exposed to the medium; he applies the mortar in a surface in front of him and at a height that stretches well beyond his height. Thus all the front parts of his body are exposed.

The details of potential dermal exposure estimation are shown in Table 14. The total potential dermal exposure of 48 sorts these tasks in the 3rd DREAM category of moderate exposure, which seems logical taking into account the nature of the task.

5.3.5 Actual exposure: Task 2 – Mortar Application

Taking into account the clothing protection factors of Table 11, the actual dermal exposure is evaluated. The results are shown in Table 15 for each body part and each task of this scenario. The total actual dermal exposure is equal to 7, i.e. corresponds to the 2nd DREAM category of very low exposure.

Table 14. Potential skin exposure: Depollutant Mortar Application Process – Task 2. Mortar Application.

Variable	Name	Formula	Value	
Intrinsic emission	E_I	$E_I=PS*C*EV*V$	$E_I=1*0.1*3*0.3=$	**0.09**
Emission to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	E_{BP}	$E_{BP}=ER_E*P_{E.BP}*I_{E.BP}*E_I$	$E_{HE}=3*10*3*0.09=$	8.1
			$E_{UA}=3*10*3*0.09=$	8.1
			$E_{FA}=3*10*3*0.09=$	8.1
			$E_{HA}=3*10*3*0.09=$	8.1
			$E_{TF}=3*10*3*0.09=$	8.1
			$E_{TB}=3*0*0*0.09=$	0
			$E_{LB}=3*3*1*0.09=$	0.81
			$E_{LL}=3*1*1*0.09=$	0.27
			$E_{FE}=3*1*1*0.09=$	0.27
Total emission	E_{TOT}	$E_{TOT}=\Sigma_{BP=1\text{-}9}E_{BP}$	$E_{TOT}=$	**41.85**
Deposition on head, upper arms, forearms, hands, torso front, torsoback, lower body part, lower legs, feet	D_{BP}	$D_{BP}=ER_D*P_{D.BP}*I_{D.BP}*Dp_{BP}*E_I$	$D_{HE}=1*3*3*1*0.09=$	0.81
			$D_{UA}=1*3*1*1*0.09=$	0.81
			$D_{FA}=1*3*3*1*0.09=$	0.81
			$D_{HA}=1*3*3*1*0.09=$	0.81
			$D_{TF}=1*3*3*1*0.09=$	0.81
			$D_{TB}=1*0*0*0*0.09=$	0
			$D_{LB}=1*1*1*1*0.09=$	0.09
			$D_{LL}=1*1*1*1*0.09=$	0.09
			$D_{FE}=1*1*1*1*0.09=$	0.09
Total deposition	D_{TOT}	$D_{TOT}=\Sigma_{BP=1\text{-}9}D_{BP}$	$D_{TOT}=$	**4.32**
Transfer to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	T_{BP}	$T_{BP}=ER_T*P_{T.BP}*I_{T.BP}*Tr_{BP}*E_I$	$T_{HE}=1*0*3*0*0.09=$	0
			$T_{UA}=1*0*3*0*0.09=$	0
			$T_{FA}=1*0*3*0*0.09=$	0
			$T_{HA}=1*10*3*1*0.09=$	27
			$T_{TF}=1*0*3*0*0.09=$	0
			$T_{TB}=1*0*3*0*0.09=$	0
			$T_{LB}=1*0*3*0*0.09=$	0
			$T_{LL}=1*0*3*0*0.09=$	0
			$T_{FE}=1*0*3*0*0.09=$	0
Total transfer	T_{TOT}	$T_{TOT}=\Sigma_{BP=1\text{-}9}T_{BP}$	$T_{TOT}=$	**27**
Potential skin exposure per body part	Skin-P_{BP}	Skin-$P_{BP}=E_{BP}+D_{BP}+T_{BP}$	Skin-$P_{HE}=$	8.91
			Skin-$P_{UA}=$	8.91
			Skin-$P_{FA}=$	8.91
			Skin-$P_{HA}=$	35.91
			Skin-$P_{TF}=$	8.91
			Skin-$P_{TB}=$	0
			Skin-$P_{LB}=$	0.9
			Skin-$P_{LL}=$	0.36
			Skin-$P_{FE}=$	0.36
Total potential skin exposure	**Skin-P_{TASK}**	**Skin-$P_{TASK}=\Sigma_{BP=1\text{-}9}$(Skin-$P_{BP}*BS_{BP}$)**	**Skin-$P_{TASK}=$**	**47.42**

Table 15. Actual skin exposure: Depollutant Mortar Application Process – Task 2. Mortar Application.

Variable	Name	Formula	Value	
Actual skin exposure for each body part	Skin-A_{BP}	Skin-A_{BP}=Skin-P_{BP}*O_{BP}*BS_{BP}	Skin-A_{HE}=	8.91
			Skin-A_{UA}=	0.24057
			Skin-A_{FA}=	0.24057
			Skin-A_{HA}=	1.0773
			Skin-A_{TF}=	0.24057
			Skin-A_{TB}=	0
			Skin-A_{LB}=	0.0243
			Skin-A_{LL}=	0.00972
			Skin-A_{FE}=	0.0324
Total actual skin exposure	**Skin-A_{TASK}**	**Skin-A_{TASK}=$\Sigma_{BP=1-9}$(Skin-A_{BP}*BS_{BP})**	**Skin-A_{TASK}=**	**7.33**

5.3.6 Potential exposure: Task 3 – Scrapping

This task involves the application of scrapping the dry mortar, i.e. solid particles are emmited. Emission is assumed again to be the dominant exposure route, but deposition will be significant as well for such a material. Transfer can be only achieved on the hands by the tool the worker uses. Moreover, in this case the worker is more exposed to the medium; he sands dry mortar in a surface in front of him and at a height that stretches well beyond his height. Thus all the front parts of his body are exposed.

The details of potential dermal exposure estimation are shown in Table 14. The total potential dermal exposure of almost 1400 sorts these tasks in the 7th DREAM category of extremely high exposure.

5.3.7Actual exposure: Task 3 – Scrapping

Taking into account the clothing protection factors of Table 11, the actual dermal exposure is evaluated. The results are shown in Table 17 for each body part and each task of this scenario. The total actual dermal exposure is equal to 280, i.e. corresponds to the 5th DREAM category of high exposure.

Table 16. Potential skin exposure: Depollutant Mortar Application Process – Task 3. Scrapping.

Variable	Name	Formula	Value	
Intrinsic emission	**E_I**	**E_I=PS*C*F*DU*SS**	**E_I=1*0.1*3*3*1=**	**0.9**
Emission to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	E_{BP}	$E_{BP}=ER_E*P_{E.BP}*I_{E.BP}*E_I$	E_{HE}=3*10*10*0.9=	270
			E_{UA}=3*10*10*0.9=	270
			E_{FA}=3*10*10*0.9=	270
			E_{HA}=3*10*10*0.9=	270
			E_{TF}=3*10*10*0.9=	270
			E_{TB}= 3*0*0*0.9=	0
			E_{LB}= 3*3*3*0.9=	24.3
			E_{LL}= 3*1*1*0.9=	2.7
			E_{FE}= 3*1*1*0.9=	2.7
Total emission	**E_{TOT}**	**$E_{TOT}=\Sigma_{BP=1\text{-}9}E_{BP}$**	**E_{TOT}=**	**1379.7**
Deposition on head, upper arms, forearms, hands, torso front, torsoback, lower body part, lower legs, feet	D_{BP}	$D_{BP}=ER_D*P_{D.BP}*I_{D.BP}*Dp_{BP}*E_I$	D_{HE}=1*10*10*1*0.9=	90
			D_{UA}=1*10*10*1*0.9=	90
			D_{FA}=1*10*10*1*0.9=	90
			D_{HA}=1*10*10*1*0.9=	90
			D_{TF}=1*10*10*1*0.9=	90
			D_{TB}=1*0*0*0*0.9=	0
			D_{LB}=1*3*3*1*0.9=	8.1
			D_{LL}=1*3*1*1*0.9=	2.7
			D_{FE}=1*3*1*1*0.9=	2.7
Total deposition	**D_{TOT}**	**$D_{TOT}=\Sigma_{BP=1\text{-}9}D_{BP}$**	**D_{TOT}=**	**463.5**
Transfer to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	T_{BP}	$T_{BP}=ER_T*P_{T.BP}*I_{T.BP}*Tr_{BP}*E_I$	T_{HE}=1*0*3*0*0.9=	0
			T_{UA}=1*0*3*0*0.9=	0
			T_{FA}=1*0*3*0*0.9=	0
			T_{HA}=1*10*3*1*0.9=	27
			T_{TF}=1*0*3*0*0.9=	0
			T_{TB}=1*0*3*0*0.9=	0
			T_{LB}=1*0*3*0*0.9=	0
			T_{LL}=1*0*3*1*0.9=	0
			T_{FE}=1*0*3*1*0.9=	0
Total transfer	**T_{TOT}**	**$T_{TOT}=\Sigma_{BP=1\text{-}9}T_{BP}$**	**T_{TOT}=**	**27**
Potential skin exposure per body part	Skin-P_{BP}	Skin-$P_{BP}=E_{BP}+D_{BP}+T_{BP}$	Skin-P_{HE}=	360
			Skin-P_{UA}=	360
			Skin-P_{FA}=	360
			Skin-P_{HA}=	387
			Skin-P_{TF}=	360
			Skin-P_{TB}=	0
			Skin-P_{LB}=	32.4
			Skin-P_{LL}=	5.4
			Skin-P_{FE}=	5.4
Total potential skin exposure	**Skin-P_{TASK}**	**Skin-$P_{TASK}=\Sigma_{BP=1\text{-}9}$(Skin-$P_{BP}*BS_{BP}$)**	**Skin-P_{TASK}=**	**1389.83**

Table 17. Actual skin exposure: Depollutant Mortar Application Process – Task 3. Scrapping.

Variable	Name	Formula	Value	
Actual skin exposure for each body part	Skin-A_{BP}	Skin-A_{BP}=Skin-P_{BP}*O_{BP}*BS_{BP}	Skin-A_{HE}=	360
			Skin-A_{UA}=	9.72
			Skin-A_{FA}=	9.72
			Skin-A_{HA}=	11.61
			Skin-A_{TF}=	9.72
			Skin-A_{TB}=	0
			Skin-A_{LB}=	0.8748
			Skin-A_{LL}=	0.1458
			Skin-A_{FE}=	0.486
Total actual skin exposure	**Skin-A_{TASK}**	**Skin-A_{TASK}=$\Sigma_{BP=1-9}$(Skin-A_{BP}*BS_{BP})**	**Skin-A_{TASK}=**	**279.98**

5.4 Demolition of Cabins (covered with nano-TiO_2 and nano-SiO_2)

This scenario relates to the demolition of two cabins covered with self-cleaning mortar (containing TiO_2) and mortar (containing SiO_2). Although these two scenarios are related to different nanomaterials (nano-TiO_2) and (nano-SiO_2) they have been grouped in this chapter because the process of demolition was performed sequentially and was the same for both, jointly with the measurement strategy followed.

5.4.1 Short description

This scenario was performed outdoors and two cabs (previously constructed by ACCIONA) were demolished one covered with depollutant mortar containing SiO_2 and the other one covered with mortar containing TiO_2 supported on sepiolite.

Figure 7. Snapshots of the cabins demolition (left & middle) and waste collection (right).

Two tasks have been considered for this scenario (Figure 7):

- Task 1 (T1): Demolition of CAB A (nano-SiO2); It includes the demolition with the excavator (T1.1) and the waste collection (T1.2).
- Task 2 (T2): Demolition of CAB B (nano-TiO_2); It includes the demolition with the excavator (T2.1) and the waste collection (T2.2).

Figure 8. Monitoring point – Operator (worker 2)

During the process, two workers were involved: one was the driver of the excavator (worker 1) and the second worker was an operator located near the place (at a distance determined by safety reasons (worker 2). Both used respirator mask FFP3. The corresponding clothing protection factors for all three tasks are show in Table 18.

Table 18. Clothing factors for the different body parts: Demolition of Cabins.

Variable	Name	Formula	Value	
Clothing factor hands	O_{HA}	O_{HA}=M*PFM$_{HA}$*RF*GC*UG*RF*BC		
			O_{HA}= no protection	1
Clothing factor other body parts	O_{BP}	O_{BP}=M*PFM$_{BP}$*RF	O_{HE}=no protection	1
			O_{UA}=0.3*0.3*0.3=	0.027
			O_{FA}=0.3*0.3*0.3=	0.027
			O_{TF}=0.3*0.3*0.3=	0.027
			O_{TB}=0.3*0.3*0.3=	0.027
			O_{LB}=0.3*0.3*0.3=	0.027
			O_{LL}=0.3*0.3*0.3=	0.027
			O_{FE}=0.03*0.3*10=	0.09

In this scenario both tasks are performed by heavy machines. The involved personnel are either inside the truck (worker 1) or an operator standing in a distance dictated by the safety regulations (worker 2). Assuming that worker 1 is in the truck with closed windows we are only going to estimate dermal exposure for the operator who stands in open air. DREAM does not distinguish between the different emission rates (which is expected to be higher for demolition than for waste collection) or the different kind of solid materials (i.e. TiO_2 vs SiO_2), therefore only one calculation will be performed for all tasks involved.

5.4.2 Potential exposure: Demolition of Cabins

The details of potential dermal exposure estimation are shown in Table 19. In this case the deposition is the main exposure route, whereas direct emission from the source is considered negligible due to the worker's distance from the cabin. Moreover, as worker 2 is operating the heavy machines remotely, he does not come in contact with the contaminated surfaces of the machines, which means that the transfer is also minimal. The total potential dermal exposure of 219 sorts these tasks in the 5^{th} DREAM category (high exposure).

5.4.3 Actual exposure: Demolition of Cabins

Taking into account the clothing protection factors of Table 18, the actual dermal exposure is evaluated. The results are shown in Table 20 for each body part and each task of this scenario. The total actual dermal exposure is equal to 34, i.e. corresponds to the lower limits of the 4^{th} DREAM category of moderate exposure. This result can be attributed to the distance of the worker from the cabin and to the fact that exposure is mainly due to deposition, which is a secondary/indirect route and losses can be assumed from the initial MNMs emission.

Table 19. Potential skin exposure: Demolition of Cabins.

Variable	Name	Formula	Value	
Intrinsic emission	**E_I**	**$E_I=PS*C*F*DU*SS$**	**$E_I=1*0.3*3*3*1=$**	**2.7**
Emission to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	E_{BP}	$E_{BP}=ER_E*P_{E.BP}*I_{E.BP}*E_I$	$E_{HE}=3*0*1*2.7=$	0
			$E_{UA}=3*0*1*2.7=$	0
			$E_{FA}=3*0*1*2.7=$	0
			$E_{HA}=3*0*1*2.7=$	0
			$E_{TF}=3*0*1*2.7=$	0
			$E_{TB}=3*0*1*2.7=$	0
			$E_{LB}=3*0*1*2.7=$	0
			$E_{LL}= 3*0*1*2.7=$	0
			$E_{FE}= 3*0*1*2.7=$	0
Total emission	**E_{TOT}**	**$E_{TOT}=\Sigma_{BP=1\text{-}9}E_{BP}$**	**$E_{TOT}=$**	**0**
Deposition on head, upper arms, forearms, hands, torso front, torsoback, lower body part, lower legs,feet	D_{BP}	$D_{BP}=ER_D*P_{D.BP}*I_{D.BP}*Dp_{BP}*E_I$	$D_{HE}=1*3*3*1*2.7=$	24.3
			$D_{UA}=1*3*3*1*2.7=$	24.3
			$D_{FA}=1*3*3*1*2.7=$	24.3
			$D_{HA}=1*3*3*1*2.7=$	24.3
			$D_{TF}=1*3*3*1*2.7=$	24.3
			$D_{TB}=1*3*3*1*2.7=$	24.3
			$D_{LB}=1*3*3*1*2.7=$	24.3
			$D_{LL}=1*3*3*1*2.7=$	24.3
			$D_{FE}=1*3*3*1*2.7=$	24.3
Total deposition	**D_{TOT}**	**$D_{TOT}=\Sigma_{BP=1\text{-}9}D_{BP}$**	**$D_{TOT}=$**	**218.7**
Transfer to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	T_{BP}	$T_{BP}=ER_T*P_{T.BP}*I_{T.BP}*Tr_{BP}*E_I$	$T_{HE}=1*0*3*0*2.7=$	0
			$T_{UA}=1*0*3*0*2.7=$	0
			$T_{FA}=1*0*3*0*2.7=$	0
			$T_{HA}=1*0*10*1*2.7=$	0
			$T_{TF}=1*0*3*0*2.7=$	0
			$T_{TB}=1*0*3*0*2.7=$	0
			$T_{LB}=1*0*3*0*2.7=$	0
			$T_{LL}=1*0*3*0*2.7=$	0
			$T_{FE}=1*0*3*0*2.7=$	0
Total transfer	**T_{TOT}**	**$T_{TOT}=\Sigma_{BP=1\text{-}9}T_{BP}$**	**$T_{TOT}=$**	**0**
Potential skin exposure per body part	Skin-P_{BP}	Skin-$P_{BP}=E_{BP}+D_{BP}+T_{BP}$	Skin-$P_{HE}=$	24.3
			Skin-$P_{UA}=$	24.3
			Skin-$P_{FA}=$	24.3
			Skin-$P_{HA}=$	24.3
			Skin-$P_{TF}=$	24.3
			Skin-$P_{TB}=$	24.3
			Skin-$P_{LB}=$	24.3
			Skin-$P_{LL}=$	24.3
			Skin-$P_{FE}=$	24.3
Total potential skin exposure	**Skin-P_{TASK}**	**Skin-$P_{TASK}=\Sigma_{BP=1\text{-}9}$(Skin-$P_{BP}*BS_{BP}$)**	**Skin-$P_{TASK}=$**	**218.94**

Table 20. Actual skin exposure: Demolition of Cabins.

Variable	Name	Formula	Value	
Actual skin exposure for each body part	$Skin\text{-}A_{BP}$	$Skin\text{-}A_{BP}=Skin\text{-}P_{BP}*O_{BP}*BS_{BP}$	$Skin\text{-}A_{HE}=$	24.3
			$Skin\text{-}A_{UA}=$	0.6561
			$Skin\text{-}A_{FA}=$	0.6561
			$Skin\text{-}A_{HA}=$	24.3
			$Skin\text{-}A_{TF}=$	0.6561
			$Skin\text{-}A_{TB}=$	0.6561
			$Skin\text{-}A_{LB}=$	0.6561
			$Skin\text{-}A_{LL}=$	0.6561
			$Skin\text{-}A_{FE}=$	2.187
Total actual skin exposure	$\mathbf{Skin\text{-}A_{TASK}}$	$\mathbf{Skin\text{-}A_{TASK}=\Sigma_{BP=1\text{-}9}(Skin\text{-}A_{BP}*BS_{BP})}$	$\mathbf{Skin\text{-}A_{TASK}=}$	**34.30**

5.5 Self-cleaning Coatings Application (containing nano-TiO_2)

This scenario relates to the application of Sol-gel coating (TiO_2) on a wall. This scenario was monitored the 29 May 2013 in a manufacturer industry provided by ACCIONA.

5.5.1 Short description

This scenario was performed outdoors. Two different sol-gel coatings were applied on a wall (4 m^2). The sol-gel A has 1.7% of commercial nano-TiO2, Aeroxide P25, from Evonix. The Sol-Gel B has 1.3% of a nano-TiO2 additive developed by TOLSA and Acciona; its composition is: 50% nano-TiO2 and 50% sepiolite (weight). It was applied 1 l of each one of the products.

The sol-gel was applied using a standard spray-gun (Figure 9). So two tasks were performed:

- Task 1-Spraying sol-gel A (nano-TiO_2)
- Task 2: Spraying sol-gel B (TiO_2-sepio)

Figure 9. Snapshot of spraying scenario.

During the process, one operator was involved who used respirator mask FFP3, gloves and a Tyvek suit. The corresponding clothing protection factors for all three tasks are show in Table 21.

DREAM was used once to estimate the dermal exposure of the involved worker, because in the model we cannot distinguish between the different MNMs (i.e. nano-TiO_2 vs TiO_2-sepio).

Table 21. Clothing factors for the different body parts: Self-cleaning Coatings Application.

Variable	Name	Formula	Value	
Clothing factor hands	O_{HA}	O_{HA}=M*PFM_{HA}*RF*GC*UG*URF*BC	O_{HA}= 0.1*1*0.3*1*1*1 *1*1=	0.03
Clothing factor other body parts	O_{BP}	O_{BP}=M*PFM_{BP}*RF	O_{HE}=0.1*0.3*0.3=	0.009
			O_{UA}=0.1*0.3*0.3=	0.009
			O_{FA}=0.1*0.3*0.3=	0.009
			O_{TF}=0.1*0.3*0.3=	0.009
			O_{TB}=0.1*0.3*0.3=	0.009
			O_{LB}=0.1*0.3*0.3=	0.009
			O_{LL}=0.1*0.3*0.3=	0.009
			O_{FE}=0.03*0.3*10=	0.09

5.5.2 Potential exposure: Self-cleaning Coatings Application

The details of potential dermal exposure estimation are shown in Table 22. We assume that the main contribution to dermal exposure is from direct emission from the spraying tool, following by deposition (due to small MNMs size) and lower transfer (basically only on the hands from the equipment). The total potential dermal exposure of 1323 sorts these tasks in the 7th DREAM category (extremely high exposure).

5.5.3 Actual exposure: Self-cleaning Coatings Application

Taking into account the clothing protection factors of Table 21, the actual dermal exposure is evaluated. The results are shown in Table 23 for each body part and each task of this scenario. The total actual dermal exposure is equal to 16, i.e. corresponds to the 3rd DREAM category of low exposure. This result can be attributed mainly to the personal protection equipment used in this scenario's tasks, which seems to be very effective in this case.

Table 22. Potential skin exposure: Self-cleaning Coatings Application.

Variable	Name	Formula	Value	
Intrinsic emission	E_I	E_I=PS*C*EV*V	E_I=1*0.3*3*1=	**0.9**
Emission to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	E_{BP}	$E_{BP}=ER_E*P_{E.BP}*I_{E.BP}*E_I$	E_{HE}=3*10*10*0.9=	270
			E_{UA}=3*10*10*0.9=	270
			E_{FA}=3*10*10*0.9=	270
			E_{HA}=3*10*10*0.9=	270
			E_{TF}=3*10*10*0.9=	270
			E_{TB}= 3*0*0*0.9=	0
			E_{LB}= 3*1*1*0.9=	2.7
			E_{LL}= 3*1*1*0.9=	2.7
			E_{FE}= 3*1*1*0.9=	2.7
Total emission	E_{TOT}	$E_{TOT}=\Sigma_{BP=1\text{-}9}E_{BP}$	E_{TOT}=	**1358.1**
Deposition on head, upper arms, forearms, hands, torso front, torsoback, lower body part, lower legs,feet	D_{BP}	$D_{BP}=ER_D*P_{D.BP}*I_{D.BP}*Dp_{BP}*E_I$	D_{HE}=1*10*10*1*0.9=	90
			D_{UA}=1*10*10*1*0.9=	90
			D_{FA}=1*10*10*1*0.9=	90
			D_{HA}=1*10*10*1*0.9=	90
			D_{TF}=1*10*10*1*0.9=	90
			D_{TB}=1*0*0*0*0.9=	0
			D_{LB}=1*1*3*1*0.9=	2.7
			D_{LL}=1*1*3*1*0.9=	2.7
			D_{FE}=1*1*1*1*0.9=	0.9
Total deposition	D_{TOT}	$D_{TOT}=\Sigma_{BP=1\text{-}9}D_{BP}$	D_{TOT}=	**456.3**
Transfer to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	T_{BP}	$T_{BP}=ER_T*P_{T.BP}*I_{T.BP}*Tr_{BP}*E_I$	T_{HE}=1*0*3*0*0.9=	0
			T_{UA}=1*0*3*0*0.9=	0
			T_{FA}=1*0*3*0*0.9=	0
			T_{HA}=1*10*3*1*0.9=	27
			T_{TF}=1*0*3*0*0.9=	0
			T_{TB}=1*0*3*0*0.9=	0
			T_{LB}=1*0*3*0*0.9=	0
			T_{LL}=1*0*3*0*0.9=	0
			T_{FE}=1*0*3*0*0.9=	0
Total transfer	T_{TOT}	$T_{TOT}=\Sigma_{BP=1\text{-}9}T_{BP}$	T_{TOT}=	**27**
Potential skin exposure per body part	Skin-P_{BP}	Skin-$P_{BP}=E_{BP}+D_{BP}+T_{BP}$	Skin-P_{HE}=	360
			Skin-P_{UA}=	360
			Skin-P_{FA}=	360
			Skin-P_{HA}=	387
			Skin-P_{TF}=	360
			Skin-P_{TB}=	0
			Skin-P_{LB}=	5.4
			Skin-P_{LL}=	5.4
			Skin-P_{FE}=	3.6
Total potential skin exposure	**Skin-P_{TASK}**	**Skin-$P_{TASK}=\Sigma_{BP=1\text{-}9}$(Skin-$P_{BP}*BS_{BP}$)**	**Skin-P_{TASK}=**	**1323.1**

Table 23. Actual skin exposure: Self-cleaning Coatings Application.

Variable	Name	Formula	Value	
Actual skin exposure for each body part	Skin-A_{BP}	Skin-A_{BP}=Skin-P_{BP}*O_{BP}*BS_{BP}	Skin-A_{HE}=	3.24
			Skin-A_{UA}=	3.24
			Skin-A_{FA}=	3.24
			Skin-A_{HA}=	11.61
			Skin-A_{TF}=	3.24
			Skin-A_{TB}=	0
			Skin-A_{LB}=	0.0486
			Skin-A_{LL}=	0.0486
			Skin-A_{FE}=	0.324
Total actual skin exposure	**Skin-A_{TASK}**	**Skin-A_{TASK}=$\Sigma_{BP=1-9}$(Skin-A_{BP}*BS_{BP})**	**Skin-A_{TASK}=**	**15.91**

5.6 Machining of Samples – Drilling

These scenarios relate to the drilling of materials from 4 applications in the scope of Scaffold; a) depollutant mortar (TiO_2), b) dslf-compacting concrete (SiO_2), c) self-cleaning coating (TiO_2), and d) fire retardant panels (nanoclays). Although these scenarios are related to different nanomaterials and have been performed in different campaigns, they have been grouped in this chapter because the process of drilling was performed similarly.

Figure 10. Snapshots of drilling scenario.

5.6.1 Short description

This scenario is being performed outside, in the dependences of Tecnalia; samples of the materials of interest for SCAFFOLD project are drilled outside of the building similar to real conditions in a construction site. Driller and samples used in the tests are common devices used in the sector. In all cases the hole drilled was 4 cm length.

The samples used in this test have been provided by Acciona and Netcomposite. For each application three types of material are being tested; 1. control A, 2. formulation B (filled with nano-objects), and formulation C (filled with nano-objects in different presentation or percentage). The samples received from ACCIONA and NETCOMPOSITE were squares of 20*20*5 cm. The samples of depollutant mortar, concrete and mortar with self-cleaning mortar were fixed in a frame (made also with mortar) to be drilled because otherwise the samples broken when the process of drilling started. The samples of composite were fixed to a table while were drilled (Figure 10). About 11-15 holes were drilled per sample.

During the task the operators wore conventional work clothes and FPP3 mask, glasses and gloves. The corresponding clothing protection factors for all three tasks are show in Table 24.

DREAM was used once to estimate the dermal exposure of the involved worker, because in the model we cannot distinguish between the different MNMs (i.e. nano-TiO_2 , SiO_2 or nanoclays).

Table 24. Clothing factors for the different body parts: Drilling.

Variable	Name	Formula	Value	
Clothing factor hands	O_{HA}	O_{HA}=M*PFM_{HA}*RF*GC*UG*URF*BC	O_{HA}= 0.1*1*0.3*1*1*1 *1*1=	0.03
Clothing factor other body parts	O_{BP}	O_{BP}=M*PFM_{BP}*RF	O_{HE}=0.1*0.3*0.3=	0.009
			O_{UA}=0.1*0.3*0.3=	0.009
			O_{FA}=0.1*0.3*0.3=	0.009
			O_{TF}=0.1*0.3*0.3=	0.009
			O_{TB}=0.1*0.3*0.3=	0.009
			O_{LB}=0.1*0.3*0.3=	0.009
			O_{LL}=0.1*0.3*0.3=	0.009
			O_{FE}=0.03*0.3*10=	0.09

5.6.2 Potential exposure: Drilling

The details of potential dermal exposure estimation are shown in Table 25. We assume that the main contribution to dermal exposure is from direct emission, following by deposition (due to small MNMs size) and lower transfer (basically only on the hands from the equipment). The total potential dermal exposure of 1239 sorts these tasks in the 7th DREAM category (extremely high exposure).

5.6.3 Actual exposure: Drilling

Taking into account the clothing protection factors of Table 24, the actual dermal exposure is evaluated. The results are shown in Table 26 for each body part and each task of this scenario. The total actual dermal exposure is almost 25, i.e. corresponds to the 3rd DREAM category of low exposure. This result can be attributed mainly to the personal protection equipment used in this scenario's tasks, which seems to be very effective in this case.

Table 25. Potential skin exposure: Drilling.

Variable	Name	Formula	Value	
Intrinsic emission	E_I	E_I=PS*C*F*DU*SS	E_I=1*0.3*3*3*1=	**2.7**
Emission to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	E_{BP}	$E_{BP}=ER_E*P_{E.BP}*I_{E.BP}*E_I$	E_{HE}=3*3*1*2.7=	24.3
			E_{UA}=3*3*1*2.7=	24.3
			E_{FA}=3*10*10*2.7=	810
			E_{HA}=3*10*10*2.7=	810
			E_{TF}=3*10*3*2.7=	243
			E_{TB}= 3*0*0*2.7=	0
			E_{LB}= 3*0*1*2.7=	0
			E_{LL}= 3*0*1*2.7=	0
			E_{FE}= 3*0*1*2.7=	0
Total emission	E_{TOT}	$E_{TOT}=\Sigma_{BP=1-9}E_{BP}$	E_{TOT}=	**1911.6**
Deposition on head, upper arms, forearms, hands, torso front, torsoback, lower body part, lower legs, feet	D_{BP}	$D_{BP}=ER_D*P_{D.BP}*I_{D.BP}*Dp_{BP}*E_I$	D_{HE}=1*3*1*1*2.7=	8.1
			D_{UA}=1*3*1*1*2.7=	8.1
			D_{FA}=1*10*3*1*2.7=	81
			D_{HA}=1*10*3*1*2.7=	81
			D_{TF}=1*10*3*1*2.7=	81
			D_{TB}=1*0*0*0*2.7=	0
			D_{LB}=1*1*1*1*2.7=	2.7
			D_{LL}=1*0*1*1*2.7=	0
			D_{FE}=1*0*1*1*2.7=	0
Total deposition	D_{TOT}	$D_{TOT}=\Sigma_{BP=1-9}D_{BP}$	D_{TOT}=	**261.9**
Transfer to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	T_{BP}	$T_{BP}=ER_T*P_{T.BP}*I_{T.BP}*Tr_{BP}*E_I$	T_{HE}=1*0*3*0*2.7=	0
			T_{UA}=1*0*3*0*2.7=	0
			T_{FA}=1*0*3*0*2.7=	0
			T_{HA}=1*10*10*1*2.7=	270
			T_{TF}=1*0*3*0*2.7=	0
			T_{TB}=1*0*3*0*2.7=	0
			T_{LB}=1*0*3*0*2.7=	0
			T_{LL}=1*0*3*0*2.7=	0
			T_{FE}=1*0*3*0*2.7=	0
Total transfer	T_{TOT}	$T_{TOT}=\Sigma_{BP=1-9}T_{BP}$	T_{TOT}=	**270**
Potential skin exposure per body part	Skin-P_{BP}	Skin-$P_{BP}=E_{BP}+D_{BP}+T_{BP}$	Skin-P_{HE}=	32.4
			Skin-P_{UA}=	32.4
			Skin-P_{FA}=	891
			Skin-P_{HA}=	1161
			Skin-P_{TF}=	324
			Skin-P_{TB}=	0
			Skin-P_{LB}=	2.7
			Skin-P_{LL}=	0
			Skin-P_{FE}=	0
Total potential skin exposure	**Skin-P_{TASK}**	**Skin-$P_{TASK}=\Sigma_{BP=1-9}$(Skin-$P_{BP}*BS_{BP}$)**	**Skin-P_{TASK}=**	**1463.8**

Table 26. Actual skin exposure: Drilling.

Variable	Name	Formula	Value	
Actual skin exposure for each body part	Skin-A_{BP}	Skin-A_{BP}=Skin-P_{BP}*O_{BP}*BS_{BP}	Skin-A_{HE}=	0.2916
			Skin-A_{UA}=	0.2916
			Skin-A_{FA}=	8.019
			Skin-A_{HA}=	34.83
			Skin-A_{TF}=	2.916
			Skin-A_{TB}=	0
			Skin-A_{LB}=	0.0243
			Skin-A_{LL}=	0
			Skin-A_{FE}=	0
Total actual skin exposure	**Skin-A_{TASK}**	**Skin-A_{TASK}=$\Sigma_{BP=1-9}$(Skin-A_{BP}*BS_{BP})**	**Skin-A_{TASK}=**	**24.63**

5.7 Machining of Samples – Sawing

These scenarios relate to the sawing of coatings based on polymers doped with carbon nanofibers (CNF). The goal of these measurements is to characterize the potential release of particles and the occupational exposure during the machining process.

5.7.1 Short description

This scenario is being performed outside, in the dependences of Tecnalia; samples of the coatings with CNF are sawed outside of the building similar to real conditions in a construction site. Saw used in the tests is a common device used in the sector. The materials sawed are polymer panels previously developed by Acciona. The panels are made with resin, mats of glass fiber and CNF (0.1 % or 0.5%).

Three formulations have been developed, Material A, control material without CNF, Material B, which contains 0.1 % of CNF and Material C which has 0.5 % of CNF. The samples received from ACCIONA were laminates with dimensions 50*50*1 cm. The sawing task is performed outside, by one operator. The sequence is, Material A; B and C; the operator made 3 cuts in each material (Figure 11).

Figure 11. Snapshot of sawing scenario.

During the task the operators wore protective glasses, gloves, FPP3 respirator and a Tyvek suit. The corresponding clothing protection factors for all three tasks are show in Table 27.

DREAM was used once to estimate the dermal exposure of the involved worker, because in the model we cannot distinguish between the two different CNF concentrations of 0.1% and 0.5% (everything <1% results in the same concentration factor for the intrinsic emission estimation).

Table 27. Clothing factors for the different body parts: Sawing.

Variable	Name	Formula	Value	
Clothing factor hands	O_{HA}	O_{HA}=M*PFM_{HA}*RF*GC*UG*URF*BC	O_{HA}= 0.1*1*0.3*1*1*1 *1*1=	0.03
Clothing factor other body parts	O_{BP}	O_{BP}=M*PFM_{BP}*RF	O_{HE}=0.1*0.3*0.3=	0.009
			O_{UA}=0.1*0.3*0.3=	0.009
			O_{FA}=0.1*0.3*0.3=	0.009
			O_{TF}=0.1*0.3*0.3=	0.009
			O_{TB}=0.1*0.3*0.3=	0.009
			O_{LB}=0.1*0.3*0.3=	0.009
			O_{LL}=0.1*0.3*0.3=	0.009
			O_{FE}=0.03*0.3*10=	0.09

5.7.2 Potential exposure: Sawing

The details of potential dermal exposure estimation are shown in Table 28. We assume that the main contribution to dermal exposure is from direct emission, following by deposition (due to small MNMs size) and lower transfer (basically only on the hands from the equipment). The released MNMs are assumed fine, sticky particles of low dustiness due to the presence of resin in the materials. The total potential dermal exposure of 413 sorts these tasks in the 6th DREAM category (very high exposure).

5.7.3 Actual exposure: Sawing

Taking into account the clothing protection factors of Table 27, the actual dermal exposure is evaluated. The results are shown in Table 29 for each body part and each task of this scenario. The total actual dermal exposure is almost 6, i.e. corresponds to the 2nd DREAM category of very low exposure. This result can be attributed mainly to the personal protection equipment used in this scenario’s tasks, which seems to be very effective in this case.

Table 28. Potential skin exposure: Sawing.

Variable	Name	Formula	Value	
Intrinsic emission	E_I	E_I=PS*C*F*DU*SS	E_I=1*0.1*3*1*1.75=	**0.525**
Emission to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	E_{BP}	$E_{BP}=ER_E*P_{E.BP}*I_{E.BP}*E_I$	E_{HE}= 3*10*3*0.525=	47.25
			E_{UA}= 3*10*3*0.525=	47.25
			E_{FA}= 3*10*3*0.525=	47.25
			E_{HA}= 3*10*10*0.525=	157.5
			E_{TF}= 3*10*10*0.525=	157.5
			E_{TB}= 3*0*1*0.525=	0
			E_{LB}= 3*1*3*0.525=	4.725
			E_{LL}= 3*0*1*0.525=	0
			E_{FE}= 3*0*1*0.525=	0
Total emission	E_{TOT}	$E_{TOT}=\Sigma_{BP=1\text{-}9}E_{BP}$	E_{TOT}=	**461.48**
Deposition on head, upper arms, forearms, hands, torso front, torsoback, lower body part, lower legs, feet	D_{BP}	$D_{BP}=ER_D*P_{D.BP}*I_{D.BP}*Dp_{BP}*E_I$	D_{HE}=1*10*1*1*0.525=	5.25
			D_{UA}=1*10*1*1*0.525=	5.25
			D_{FA}=1*10*1*1*0.525=	5.25
			D_{HA}=1*10*3*1*0.525=	15.75
			D_{TF}=1*10*3*1*0.525=	15.75
			D_{TB}=1*0*1*0*0.525=	0
			D_{LB}=1*1*1*1*0.525=	0.525
			D_{LL}=1*1*1*1*0.525=	0.525
			D_{FE}=1*1*1*1*0.525=	0.525
Total deposition	D_{TOT}	$D_{TOT}=\Sigma_{BP=1\text{-}9}D_{BP}$	D_{TOT}=	**48.825**
Transfer to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	T_{BP}	$T_{BP}=ER_T*P_{T.BP}*I_{T.BP}*Tr_{BP}*E_I$	T_{HE}=1*0*1*0*0.525=	0
			T_{UA}=1*0*1*0*0.525=	0
			T_{FA}=1*0*1*0*0.525=	0
			T_{HA}=1*10*3*1*0.525=	15.75
			T_{TF}=1*0*1*0*0.525=	0
			T_{TB}=1*0*1*0*0.525=	0
			T_{LB}=1*0*1*0*0.525=	0
			T_{LL}=1*0*1*0*0.525=	0
			T_{FE}=1*0*1*0*0.525=	0
Total transfer	T_{TOT}	$T_{TOT}=\Sigma_{BP=1\text{-}9}T_{BP}$	T_{TOT}=	**15.75**
Potential skin exposure per body part	Skin-P_{BP}	Skin-$P_{BP}=E_{BP}+D_{BP}+T_{BP}$	Skin-P_{HE}=	52.5
			Skin-P_{UA}=	52.5
			Skin-P_{FA}=	52.5
			Skin-P_{HA}=	189
			Skin-P_{TF}=	173.25
			Skin-P_{TB}=	0
			Skin-P_{LB}=	5.25
			Skin-P_{LL}=	0.525
			Skin-P_{FE}=	0.525
Total potential skin exposure	**Skin-P_{TASK}**	**Skin-$P_{TASK}=\Sigma_{BP=1\text{-}9}$(Skin-$P_{BP}*BS_{BP}$)**	**Skin-P_{TASK}=**	**413.11**

Table 29. Actual skin exposure: Sawing.

Variable	Name	Formula	Value	
Actual skin exposure for each body part	$Skin\text{-}A_{BP}$	$Skin\text{-}A_{BP}=Skin\text{-}P_{BP}*O_{BP}*BS_{BP}$	$Skin\text{-}A_{HE}$=	0.4725
			$Skin\text{-}A_{UA}$=	0.4725
			$Skin\text{-}A_{FA}$=	0.4725
			$Skin\text{-}A_{HA}$=	5.67
			$Skin\text{-}A_{TF}$=	1.55925
			$Skin\text{-}A_{TB}$=	0
			$Skin\text{-}A_{LB}$=	0.04725
			$Skin\text{-}A_{LL}$=	0.00473
			$Skin\text{-}A_{FE}$=	0.04725
Total actual skin exposure	$Skin\text{-}A_{TASK}$	$Skin\text{-}A_{TASK}=\Sigma_{BP=1\text{-}9}(Skin\text{-}A_{BP}*BS_{BP})$	**$Skin\text{-}A_{TASK}$=**	**5.61**

5.8 Summary of Simulations Results

Table 30. DREAM category for total potential and actual dermal exposure per scenario and task, if applicable. (PPE: Personal Protective Equipment)

Scenario	Contaminant	PPE	Dermal Exposure: DREAM category Potential	Actual
1-2. Nano-TiO_2 Manufacturing Process – Collection (T3) or Cleaning (T4)	Dry nano-TiO_2 (solid)	–Mask: Moldex FFP3 –Gloves: (2 pairs) Dermic gloves –Clothes: Tyvek suit	7 – Extremely High	5 - High
1-2. Nano-TiO_2 Manufacturing Process – Transfer (T5)	Dry nano-TiO_2 (solid)	(task performed under fume hood)	7 – Extremely High	3 - Low
3. Depollutant Mortar Manufacturing Process (per Task)	Dry nano-TiO_2 (solid)	- Mask: Moldex FP3 - Gloves Rubberex Heveaprene	7 – Extremely High	6 – Very High
4. Depollutant Mortar Application – Mortar Mixing (T1)	Dry nano-TiO_2 (solid)	– Mask: Moldex FFP3 – Gloves: Junit 8002IB	6 – Very High	3 - Low
4. Depollutant Mortar Application – Mortar Application (T2)	Nano-TiO_2 in the wet mortar (liquid)	– Mask: Moldex FFP3 – Gloves: Junit 8002IB	4 – Moderate	2 – Very Low
4. Depollutant Mortar Application – Scrapping (T3)	Nano-TiO_2 in the dry mortar (solid)	– Mask: Moldex FFP3 – Gloves: Junit 8002IB	7 – Extremely High	5 - High
5. Demolition of cabins (per Task)	Nano-TiO_2 or Nano-SiO_2 (solid)	– Mask: Moldex FP3	5 – High	4 – Moderate
6. Self-cleaning coating application (per Task)	Nano-TiO_2 in sol-gel (liquid)	–Mask: Moldex FFP3 –Gloves: Junit 8002 IB –Clothes:Tyveck suit	7 – Extremely High	3 – Low
7. Machining of Samples – Drilling	Nano-TiO_2 or Nano-SiO_2 or Nanoclay in the dry wall treatment (solid)	- Mask: Moldex FFP3 - Glasses - Gloves: Junit 8002 IB	7 – Extremely High	3 – Low
8. Machining of Samples – Sawing	Carbon nanofibers (CNF) in polymer (solid)	-Mask: Moldex FFP3 - Glasses - Gloves: Junit 8002 IB - Clothes:Tyveck suit	6 – High	2 – Very Low

In Table 30, the results of DREAM model are summarized for all exposure scenarios and tasks, if applicable. The personal protective equipment (PPE) is also included in the table, because it is the parameter that differentiates potential dermal exposure, which refers to deposition of the contaminant of interest on clothing and uncovered skin, from actual dermal exposure. It should be noted that both potential and actual dermal exposure in the table corresponds to the total exposure for the whole body. The findings demonstrate clearly the importance of PPE; use of the appropriate PPE results in differences of up to 4 DREAM categories between potential and actual dermal exposure (e.g. for Scenarios 1-2 T5, 6, 7 and 8).

In Table 31 the potential and actual dermal exposure as estimated with DREAM model is given only for hands. Exposure (potential and actual) is given in DREAM units, because there is no categorization for specific body parts in the model. The use of gloves reduces the dermal exposure several orders of magnitude (comparison between potential and actual exposure), as expected, and in all examined cases the actual dermal exposure for hands is expected to be low.

Table 31. Potential and actual dermal exposure for hands as estimated with DREAM model and the corresponding SEM observation for each scenario and task, if applicable.

			Hands Dermal Exposure: DREAM units		
Scenario	**Contaminant**	**Gloves**	**Potential**	**Actual**	**SEM observation**
1-2. Nano-TiO_2 Manufacturing Process – Collection (T3) or Cleaning (T4)	Dry nano-TiO_2 (solid)	2 pairs	4500	40.5	No penetration
1-2. Nano-TiO_2 Manufacturing Process – Transfer (T5)	Dry nano-TiO_2 (solid)	2 pairs	3060	28	No penetration
3. Depollutant Mortar Manufacturing Process (per Task)	Dry nano-TiO_2 (solid)	1 pair	387	39	No penetration
4. Depollutant Mortar Application –Mixing (T1)	Dry nano-TiO_2 (solid)	1 pair	32	1	No penetration
4. Depollutant Mortar Application – Application (T2)	Nano-TiO2 in the wet mortar (liquid)	1 pair	36	1	No penetration
4. Depollutant Mortar Application – Scrapping (T3)	Nano-TiO_2 in the dry mortar (solid)	1 pair	387	12	Not performed
5. Demolition of cabins (per Task)	Nano-TiO_2 or Nano-SiO_2 (solid)	No	24	24	Not performed
6. Self-cleaning coating application (per Task)	Nano-TiO_2 in sol-gel (liquid)	1 pair	387	12	No penetration
7. Machining of Samples – Drilling	Nano-TiO_2 or Nano-SiO_2 or Nanoclay in the dry wall treatment (solid)	1 pair	1161	35	Not performed
8. Machining of Samples – Sawing	Carbon nanofibers (CNF) in polymer (solid)	1 pair	189	6	Not performed

Observations of the gloves worn by the workers during the pilot study by Vaquero Moralejo *et al.* (2014) under a Scanning Electron Microscope (SEM) in the framework of D4.6 of the project showed that there is no evidence of particles penetration through the gloves (last column in In Table 30, the results of DREAM model are summarized for all exposure scenarios and tasks, if applicable. The personal protective equipment (PPE) is also included in the table, because it is the parameter that differentiates potential dermal exposure, which refers to deposition of the contaminant of interest on clothing and uncovered skin, from actual dermal exposure. It should be noted that both potential and actual dermal exposure in the table corresponds to the total exposure for the whole body. The findings demonstrate clearly the importance of PPE; use of the appropriate PPE results in differences of up to 4 DREAM categories between potential and actual dermal exposure (e.g. for Scenarios 1-2 T5, 6, 7 and 8).

In Table 31 the potential and actual dermal exposure as estimated with DREAM model is given only for hands. Exposure (potential and actual) is given in DREAM units, because there is no categorization for specific body parts in the model. The use of gloves reduces the dermal exposure several orders of magnitude (comparison between potential and actual exposure), as expected, and in all examined cases the actual dermal exposure for hands is expected to be low.

Table 31), therefore there is no actual dermal exposure on hands. This contradicts the model's estimates, where low to very low exposure is predicted for all examined scenarios. This "overestimation" of exposure from DREAM is attributed to the fact that the corresponding parameter in the model does not become equal to zero in no occasion; even if the gloves are non-woven and considered impermeable this parameter assumes the value 0.03, i.e. it allows the user to take a small safety factor in the calculations.

6. CONCLUSIONS

In the present study the applicability of already developed dermal-exposure models, which are suitable for general chemicals and biological agents, to manufactured nanomaterials (MNMs) exposure assessment was investigated. In particular, we wanted to find out if any of the existing models are suitable to assess dermal exposure to MNMs during the processes and for the nanomaterials of interest for the SCAFFOLD project.

Literature research showed that up to now there is no dermal exposure model dedicated to nanomaterials in general. On the other hand, some dermal exposure models for general chemicals and/or biological agents were found and investigated for their applicability in the SCAFFOLD project and its purposes. These models are the EASE model, the RISKOFDERM and the DREAM model.

In summary, EASE (Estimation and Assessment of Substance Exposure) is a general model that has been proposed for the prediction of workplace exposure to a wide range of substances hazardous to health for regulatory risk assessments. However, in separate studies it was found that EASE overestimates of actual dermal exposure and, although, it has a number of characteristics that describe exposure, it is still based on many simplifications and does not include a wide range of human and workplace factors. Moreover, the EASE model was not originally developed to take into account dusts and powders.

RISKOFDERM is a dermal exposure model designed to meet the needs of REACH and therefore addresses a large variety of different scenarios. The model exclusively predicts potential exposures. Further, it assumes a cumulative, linear relationship between task duration and dermal loading. However, scenarios that are particularly relevant for metals and metal compounds and are assumed to be associated with the highest level of skin exposure (such as bagging, mixing and unloading) are not addressed in this model.

Finally the DREAM (DeRmal Exposure Assessment Model) is an observational, semi-quantitative method proposed for the assessment of dermal exposures in occupational settings using pre-assigned default values. The outcome is a numerical estimate of exposure levels (categorized into seven levels from zero to extremely high) both on outside clothing layers and uncovered skin (potential dermal exposure) as well as on skin (actual dermal exposure) of workers performing a certain task. DREAM also attempts to provide an insight into the distribution of dermal exposure over the body, and indicates by which routes dermal exposure takes place.

The study of the aforementioned dermal exposure models showed that EASE model is not suitable for the purposes of SCAFFOLD project due to the variety of simplifications that employs, but most importantly because it was not developed for dusts and powders which are very often the state were the MNMs of interest are found in construction industry.

On the other hand, both RISKOFDERM and DREAM seemed to be relevant for SCAFFOLD, although none of them included a nanomaterial specific category. Therefore, these two models was applied in order to estimate the dermal exposure of a worker during spraying a sol-gel containing TiO_2 nanoparticles on a vertical wall. The inputs for RISKOFDERM included information regarding the settings of the task, the distance and position of the worker relative to the contaminant source, the spraying rate and the physical state of the sprayed material (liquid or solid). The model's output is the potential dermal exposure on hands and the rest of the body in mL/min and it is given as a percentile output, i.e. an exposure value below which the estimated exposure will be with a probability equal to the percentile value. As proven during the experimental pilot study by Vaquero Moralejo *et al*. (2014), there was no penetration of nanomaterials through the protective gloves of the personnel, therefore no wipe tests were performed and, consequently, dermal exposure on the hands of the workers was not found quantitatively. Therefore, the output of RISKOFDERM cannot be evaluated in the light of the present project's outputs and, thus, it was decided not to use it further.

The application of the DREAM model in the same exposure scenario (spraying of nano-TiO_2 containing sol-gel), involved the determination of a variety of parameters; from physicochemical characteristics of the material of interest to the description of the task undertaken and the personal protective equipment used by the worker during the task. As a result we obtained both the potential and the actual dermal exposure for the task and their distribution on nine different body parts. The results are given as a (dimensionless) number and the task can be sorted in one of the seven DREAM categories based on either the potential or the actual exposure. The semi-quantitative DREAM was found to be more relevant to the purposes of SCAFFOLD as its results could be, at least qualitatively, compared with the experimental observations of the project's studies.

On this ground, DREAM was used to estimate the potential and actual dermal exposure of workers based on project's deliverable 3.4 that describes the pilot, experimental study of a variety of scenarios for occupational exposure to MNMs, all of which are relevant to tasks and processes performed really in the construction industry. The study of these scenarios with DREAM, showed that the model can give logical/meaningful predictions of the dermal exposure. However, it should be noted that some of the parameters involved in the estimation of the exposure, could be rather subjective and could be based on the intuition/experience of the observer (especially in the total lack of measurements). Therefore, it is possible different observers to draw different conclusions, although between experienced observers the results are not expected to differ greatly.

Overall, with careful application DREAM can be a powerful triage tool; by ranking of tasks and jobs, it helps to prioritize expensive in both efforts and resources experimental measurements by providing information in order to determine who, where, and what to measure. Therefore, it seems to be suitable for the purposes of SCAFFOLD.

8. LIST OF TABLES AND FIGURES

8.1. LIST OF FIGURES

8.2 LIST OF TABLES

7. REFERENCES

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