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

GUIDANCE ON HEALTH SURVEILLANCE IN RELATION TO MNMs FOR WORKERS IN THE CONSTRUCTION INDUSTRY

Scaffold Public Documents - Ref.: Scaffold SPD12

Eija-Riitta Hyytinen, Virpi Väänänen, Sanni Uuksulainen, Helene Stockmann-Juvala, Panu Oksa,
Finnish Institute of Occupational Health (FIOH)

26/09/2014

The Scaffold research has received funding from the European Community's Seventh Framework Programme (FP7/20072013) under grant agreement number 280535.

INDEX

1. EXECUTIVE SUMMARY

In the construction industry, nanotechnology creates the possibility to produce materials with novel functionalities and improved characteristics. Products containing nanomaterials, so called nanoproducts, have been developed for cement, wet mortar and concrete, paints, coatings, insulation materials, glass, and infra-structural materials. They can be used on their own or in combination with other materials to achieve weight reduction or improved functionalities such as higher durability, fire resistance, thermal stability, transfer, self-cleaning, and photocatalytic properties.

The use of nanomaterials in construction products is increasing. Workers may come into contact with nanomaterials when using objects containing nanomaterials. **Inhalation** is the most common route of exposure to nanoparticles (NPs) at the workplace. In the construction industry, **workers' exposure to NPs may occur during activities generating dust** (handling of free particles, cutting, sanding, drilling, or machining materials containing NPs) **or in applications involving spraying**, which can result in aerosol formation.

There is some concern that nanomaterials may be more hazardous to humans than the same material at a macro scale; because of their small size, and also due to their shape, chemical nature and surface characteristics. The majority of materials are most likely not hazardous, at least at the exposure concentrations that workers or consumers come into contact with them. However, some indications of hazardous effects have been observed in studies using cell cultures or test animals. The most significant effects have been found in the lungs of test animals, for example, signs of inflammation. Some nanomaterials may also affect the cardiovascular system.

The following recommendations are given to workplaces in the construction industry where workers are exposed to nanomaterials, dusts and other substances which may potentially cause adverse health effects:

- Identify the used products, also those containing nanomaterials
    - List the used products
    - For identification, read **the Material Safety Data Sheet (MSDS)** of the product, and if the MSDS is not available, request **a Technical information sheet** from the manufacturer or distributor of the product
    - If you are unsure of the content of the product you may find more information in **the databases or registries on nanomaterial-containing products,** for example, Nanowerk (German), Nanodaten (German), Nanoliste (German) and Nanodatabases (Danish)
    - You may also contact the national authorities or specialist and research institutions.
- Identify the potential exposure sources and conduct a risk assessment using, for example, Control Banding (CB) methods or the help of experts
    - Identify the tasks in which the products are used, the processes, and possible emissions.
    - Identify potentially exposed workers
    - Evaluate the exposure and risk levels of nanomaterials at work

- Implement the required engineering controls and other essential risk management measures
- For workers using nanomaterials, establish a nanoexposure register (who, where, how, how often)
    - Add to the register the products that contain nanomaterials, the likely exposed workers, activities and tasks, and the estimated level of exposure
    - The nanoexposure register provides an opportunity to assess the level of exposure and determine exposure-disease (health effect) associations in the future
- **Continue applying the established medical surveillance approaches for construction workers**
    - **Periodic health examination every 1 to 5 years**
- **For workers likely to be exposed to nanomaterials of high concern:**
    - **Follow-up, focusing on respiratory (and cardiovascular) systems**

2. OBJECTIVES

The objective of this work is to help companies and medical staff identify workers exposed to nanomaterials in the construction industry. This guidance proposes a procedure for monitoring the health of nanomaterial-exposed workers.

In connection with this work, and on the basis of this report, a short (4 pages) fact sheet has been created for occupational health care professionals. The fact sheet summarizes the main issues regarding handling and exposure to nanomaterials in the construction sector that should be noticed by health care professionals.

3. SCOPE

This guidance supports and encourages companies in the construction sector and their occupational health services to monitor the health of nanomaterial-exposed workers.

4. NANOMATERIALS IN THE CONSTRUCTION INDUSTRY

What are nanomaterials?

Nanomaterials are materials containing particles with one or more dimensions between 1 and 100 nm (EU 2011). They may be natural, incidental or manufactured materials. A large number of nanomaterials are intentionally manufactured and this guidance focuses specifically on these materials.

What is their role in the construction industry?

The field of nanotechnology is growing rapidly, and the use of nanomaterials is becoming more common at workplaces as well as in our daily lives. In the construction industry, nanotechnology makes it possible to produce materials with novel functionalities and improved characteristics. Nanoproducts for construction purposes have been developed for cement, wet mortar and concrete, paints, coatings, insulation materials, glass and infra-structural materials. They can be used on their own or in combination with other materials to achieve weight reduction or improved functionalities such as higher durability, fire resistance, thermal stability, transfer, self-cleaning and photocatalytic properties. Workers can come into contact with nanomaterials when using a nanomaterial-containing product and need to be protected from potential health hazards.

4.1 EU legislation concerning nanomaterials

Work in the construction industry is associated with various health and safety risks. According to EU Directive 89/391/EEC, employers must conduct regular workplace risk assessments and put adequate prevention measures in place. This also applies to the use of and potential risks related to nanomaterials in the workplace.

The definition of a "substance" in the REACH legislation (Registration, Evaluation and Authorization of Chemicals; EU/1907/2006) also covers nanomaterials. The general obligations under REACH, such as the registration of substances manufactured or imported to the EU at volumes of 1 tonne or more, and the provision of information in the supply chain, apply as for any other substance. Another important regulation in place for substances and mixtures is the CLP Regulation (**C**lassification, **L**abelling and **P**ackaging of substances and mixtures; EU/1272/2008). Nanomaterials that fulfil the criteria for classification as hazardous under the CLP Regulation must be classified and labelled. (ECHA, the European chemicals agency, REACH pages: http://echa.europa.eu/regulations/reach), CLP pages: http://echa.europa.eu/regulations/clp).

4.2 Nanoproducts used in the construction industry

Currently nanotechnological applications are being used/under development in, for example, cement and concrete products, paints and coatings, and insulation materials (van Broekhuizen and van Broekhuizen 2009). An overview of the nanomaterials most often applied in products in the construction industry is given in Table 1.

Table 1: Products containing nanomaterials used in the construction industry (van Broekhuizen et al. 2011, Elvin G 2007, http://www.scaffold.eu-vri.eu/).

Nanomaterial	Examples of products used in construction industry
Titanium dioxide (TiO_2)	Concrete, cement, mortar, paints, coatings, glass, insulation material
Silica (SiO_2)	Concrete, cement, paints, coatings, glass, insulation material,
Nanoclay	Additive in composites
Carbon nanotubes and nanofibres	Paints, mortar, additive in composites
Zinc oxide	Coatings
Nanocellulose	Insulations
Copper oxides	Wood preservative
Silver NPs	Paints, coatings

5. HOW DO YOU KNOW THAT A PRODUCT CONTAINS NANOPARTICLES?

The primary source of information for the prevention of the risks posed by hazardous substances at the workplace is the **Material Safety Data Sheet (MSDS)**. In many cases, MSDSs contain little or no information about the presence of nanomaterials and their characteristics. This is especially problematic further down the supply chain. On the basis of one survey conducted in the construction industry in 2009, most workers and employers are not fully aware or informed of the presence of nanoproducts at their workplace (van Broekhuizen and van Broekhuizen 2009). Employers and employees are therefore advised to contact suppliers directly to request additional information about the composition of the products.

Some databases designed for the input of data on nanoproducts currently exist:

- Nanowerk (German),http://www.nanowerk.com/phpscripts/n_dbsearch.php
- Nanodaten (German),http://www.nanodaten.de/index2.php
- Nanoliste(German),http://www.bund.net/nc/themen_und_projekte/nanotechnologie/nanoproduktdatenbank/produktsuche/ , and
- Nanodatabases (Danish) http://nanodb.dk/en/products/.

Industries, research organizations and authorities have established approaches based either on voluntary reporting or mandatory reporting. As of 2013, reporting nanomaterials is mandatory in France. In June 2014, the Danish order on the Nano Products Register entered into force, and in Belgium, registration of products with nanomaterials will start at the beginning of 2016. Many other countries, such as Norway, Sweden and Italy are considering mandatory reporting schemes. Germany, the United Kingdom and Ireland have voluntary reporting. According to the participants of the European Conference on Nanomaterials, held in April 2013, EU registration of nanomaterials is preferred over a series of varying national databases, but the main problem seems to be deciding on the required level of information on nanomaterials (http://nanotech.lawbc.com/uploads/file/00112829.PDF).All the reporting systems aim to increase knowledge regarding the nanomaterials and nanoproducts placed on the market, gather information for risk assessment, and provide information on nanomaterials and nanoproducts for workers and the public. Databases and reporting schemes can be found at the following NIA website (Nanotechnology Industries Association): http://www.nanotechia.org/services/databases-reporting-schemes.

In order to determine whether a product contains nanomaterials:

- Read the **MSDS of the product**
- If the MSDS is not available, request a **Technical information sheet** from the product's manufacturer or distributor of
- If you are unsure of the content of the product, you may find more information in the **databases or registries** on nanomaterial-containing products
- You may also contact the national authorities or specialist and research institutions

Risk communication can be challenging in the construction industry

Subcontracting of construction work is very common. Potential occupational risks associated with nanomaterials must be properly identified, assessed and communicated before scheduling and carrying out subcontracted construction work. Contracted jobs can be particularly risky, as they are carried out on host company premises, usually in situations that are unfamiliar to subcontractors' workers, who may thus be exposed to unknown hazards. Lack of information about NPs that could be present in the used or processed construction materials makes it difficult to adequately assess and prevent risks.

6. WORKERS' EXPOSURE TO NANOMATERIALS IN THE CONSTRUCTION INDUSTRY

There are three main routes of exposure to nanomaterials at the workplace:

Inhalation is the most common route of exposure. In the construction industry, exposure through inhalation can especially occur in activities generating dust (cutting, sanding, drilling or machining), or in applications involving spraying, which can result in aerosol formation. Following inhalation, nanomaterials might cross the pulmonary epithelium, enter the bloodstream and reach further organs and tissues.

Dermal penetration is still being investigated. The skin is generally considered a good barrier against particles, including NPs: intact skin is most likely an efficient barrier. However, the penetration of NPs through damaged or diseased skin, which ends up in the systemic circulation, may be possible. Thus, the use of protective clothing and gloves when handling nanomaterials is recommended.

Ingestion of NPs primarily results from hand-to-mouth transfer from contaminated surfaces. Ingestion may also accompany inhalation exposure if a portion of the inhaled particles are transported from the airways to the mouth and swallowed.

Workers' exposure to NPs may occur during

- the manufacture of products containing nanomaterials for the construction industry

- work with products containing nanomaterial (a ready-to-use product or multicomponent product that is mixed on site)
- the processing of a product containing nanomaterial (e.g. cutting, drilling, sanding)
- the use of sprays containing nanomaterials (e.g. in coating or painting)

Factors affecting exposure to engineered nanomaterials include:

- the form of material: Is the nanomaterial "free" or bound to some other matrices , for example, liquid
- the release of NPs from the product during processing
- the amount of material being used
- the frequency and duration of use
- the risk management measures used

As regards the construction sector, very limited amounts of data are available on exposure to nanomaterials. Exposure to dispersed NPs was measured during the use of nanoproducts in two different companies in the following work situations: spraying a liquid window coating, applying a cement repair mortar and nano-concrete filling (van Broekhuizen et al. (2011)). Personal exposure assessment and source identification measurements were carried out during the activities (Table 2). The 8-h TWA exposure was calculated on the basis of the actual working period with products containing NPs on the days of the measurements, and corrected for local background concentration. All the calculated 8-h TWA exposures of NPs remained well below the reference value levels at the construction sites. The background concentration, the use of electrical equipment, heaters, diesel aggregates, and smoking were identified as potential confounding factors in nanomaterial measurement. (van Broekhuizen et al. (2011))

Table 2. Personal exposure assessment and source identification measurements carried out at construction sites (van Broekhuizen et al. (2011))

Work situation	Nanomaterial	Measurement location	Workers' exposure to NPs		
			Min (N_p/cm^3)	Max (N_p/cm^3)	AM (N_p/cm^3)
1. Company 1: Spraying Self-cleaning Coating	TiO_2 (anatase)	Personal exposure during spray activities	9 512	16 337	12 219
		Background	7 195	15 696	11 898
2. Company 2: Location 1 Mixing mortar	SiO_2 (amorphous) NanoCrete R4	Personal exposure: (NanoCrete mixing)	45 429	641 074	199 508
		Background	6 177	73 928	20 763
3. Company 2: Location 2 Mixing and handling repair mortar	SiO_2 (amorphous) NanoCrete R4	Personal exposure: (NanoCrete mixing)	6 107	71 519	13 983
		Background	5 964	13 310	8 844
		Background in workers' canteen	59 957	115 011	79 619
		Direct emission mixer	6 896	114 962	49 978
4. Company 2: Location 3 Drilling cured concrete mortar	SiO_2 (amorphous) NanoCrete R4	Drilling in NanoCrete concrete, near field	7 416	52 732	29 545
		Drilling in normal concrete, near field	7 886	20 068	15 960

	Up-wind location	Drilling machine idle-running	9 743	83 545	39 033
	Down-wind location	Drilling in NanoCrete concrete, near field	7 043	164 424	70 981
		Drilling in normal concrete, near field	10 075	66 079	22 889
		Drilling machine idle-running	10 656	572 410	195 616
		Background	5 611	11 346	7 605

N_P/cm^3 = number of NPs/cm^3, *AM* = arithmetic mean, NanoCrete R4 = the mortal material

The *near field* is defined as a distance of 1–2 m from activities with a dispersive use of nanomaterials. The background for situations 1, 2 and 3 was measured preceding the activities that use NPs. The background for situation 4 was measured at a larger distance in an up-wind position. Direct emissions from idle-running electrical equipment were measured without the use of products containing NPs. The nanomaterial used in Situation 1 concerns a waterborne suspension of nano-TiO_2, while situations 2 and 3 concern the mixing of dry nanomaterial. Situation 4 concerns the release of nanomaterials from drilling activities in cured concrete.

The EU Scaffold project (http://www.scaffold.eu-vri.eu/) has provided new information on workers' exposure to nanomaterials in the construction industry. Coating applications using spraying resulted in a high increase of particle concentration during the work task. The range of the released particles was 10 nm – 10 µm. A high, short-term increase of particle concentration was also observed during the machining of products containing nanomaterials: depollutant mortar, self-cleaning coating, self-compacting concrete, and panels. In addition, procedures such as adding nanomaterial, bagging or mixing products containing nanomaterials were identified as potential tasks involving exposure to nanomaterials. Number concentrations were the best measurement metrics in these tasks, while the measured mass concentrations were below the limit of detection and did not show any difference between concentrations when nanomaterials were used and the normal background concentration of particles.

7. HEALTH EFFECTS OF NANOMATERIALS

Because of their small size, but also due to their shape, chemical nature and surface characteristics, there is some concern that nanomaterials may be more hazardous to humans than the same materials at macro scale. Information from research and animal studies on nanomaterials has identified some potential safety hazards and health effects.

So far, the potential health effects of only a small fraction of the existing hundreds or thousands of nanomaterials have been studied. Most likely, the majority of materials are not hazardous, at least at the exposure concentrations relevant to workers or consumers. However, some indications of hazardous effects of certain nanomaterials have been observed in studies using cell cultures or test animals. The most significant effects have been found in the lungs of test animals, and include inflammation, tissue damage, oxidative stress, cytotoxicity, and fibrosis and tumour generation. Some nanomaterials may also affect the cardiovascular system. (For review of health effects of nanomaterials see Alenius et al. 2014; DFG 2013; Savolainen et al. 2010).

As scientific knowledge regarding the health hazards caused by nanomaterials in humans is lacking, there are concerns that some nanomaterials may attribute to chronic respiratory diseases such as asthma or chronic obstructive pulmonary disease (COPD) and induce lung infections, the appearance of fibrosis or even lung cancer. Certain types of rigid fibrous nanomaterials in particular have been evaluated as potentially harmful (Donaldson et al. 2013).These concerns can be considered relevant, since fibrotic effects have been observed in occupational lung diseases associated with workplace exposures to different types of inhaled particles and fibres.

Furthermore, as the specific effects of NPs (especially poorly soluble or insoluble ones) may be so-called particle effects, and not related to their chemical composition, their expected health effects may resemble those associated with pollution-related ultrafine particles. Epidemiological data link acute exposure to pollution-related ultrafine particles to sudden cardiac death, which is in part due to acute ischemic events (Franchini and Mannucci 2011; Weichenthal 2012).

Below are a few examples of nanomaterials to which construction workers may be exposed, and their potential health hazards:

- **Titanium dioxide (TiO_2)** Experimental studies shown that NPs have inflammagenic, oxidative and probably genotoxic effects. The International Agency for Research on Cancer (IARC) has classified inhaled TiO_2 as possibly carcinogenic to humans (Group 2B, IARC 2010). There is, however, no harmonized classification for TiO_2 under the CLP regulation in the EU.
- Some types of **carbon nanotubes and nanofibres** may be capable of causing lung inflammation and fibrosis, but others have not shown any such effects in experimental tests (NIOSH 2013). In 2014 IARC decided to classify one certain type of carbon nanotubes (MWCNT-7) as possibly carcinogenic to humans (Group 2B). Other types of carbon nanotubes were categorised as not classifiable as to their carcinogenicity to humans (Group 3) (Grosse et al. 2014).
- **Silica NPs (nanosized crystalline silica and amorphous silica)** may induce lung inflammation, granuloma formation and focal emphysema. The effects induced by amorphous silica are, in contrast to crystalline silica, reversible upon cessation of exposure (Napierska et al. 2010)

8. RECOMMENDED OCCUPATIONAL EXPOSURE LIMIT VALUES

Currently there are no official health-based Occupational Exposure Limit Values (OELs) that especially address nanomaterials in the European Union or in the Member States. OELs are lacking because toxicological and epidemiological studies are incomplete, the relevant exposure scenarios are not well known, and debates regarding which measurement metrics should be used are ongoing (Schulte et al. 2010; van Broekhuizen et al, 2012).

The Scaffold project's evaluations resulted in the following **recommendations for limit values**for the exposure to specific nanomaterials:

- **Titanium dioxide**: an OEL of 0.1 mg/m^3 (8 h) is suggested in order to protect workers from its potential health hazards, which are mainly related to local inflammatory effects in the lungs.
  The value is in the same size range as the recommended exposure limit of 0.3 mg/m^{3}for ultrafine TiO_2, proposed by NIOSH (2011).

- **Amorphous silicon dioxide**: an OEL of 0.3 mg/m^3 (8 h) is suggested, based on data showing that exposure to silicon dioxide may induce pulmonary effects, which, however, seem to be reversible upon cessation of exposure. The OEL is not applicable for nanomaterials containing crystalline silica.
  The value is identical to the MAK value for fine silica fume dust (DFG 1991) and the current DNEL value for amorphous silicon dioxide (ECHA 2014).

Within the construction sector, exposure to different kinds of dust is extremely common. Many nanomaterials are not mainly present as primary particles in workplace air, but rather as **aggregates or agglomerates** with a diameter of > 100 nm. For these cases, our **recommended 8 h OELs for general, inert dust** are 0.3 mg/m^3 for the respirable fraction, and 4 mg/m^3 for the inhalable fraction. These values can also be applied to any other types of inert, non-toxic dust measured at the worksite. For risk assessment purposes, in these cases it is always relevant to take into account national or other OELs given for the substance in bulk form, if such have been published.

The application of a precautionary approach is supported in cases with no substance-specific recommended limit values. In the Netherlands and in Germany, Provisional Nano Reference Values (NRV) (Table 3) are used as an accepted tool for precautionary risk management (SER 2012, IFA 2014). The Finnish Institute of Occupational Health also recommends the same values (FIOH 2013). These values are based on levels that are technically possible to measure, and are not health-based. They are intended to be provisional, and in use temporarily as long as substance-specific data is not available.

As regards exposure in the construction industry, the provisional Nano Reference Values are applicable for the assessment of exposure to, for example, fibrous nanomaterials, nanoclays and polystyrene as primary particles (for larger aggregates, see the earlier on this page).

Table 3. Provisional Nano Reference Values (SER 2012, IFA 2014)

Description	Benchmark level (8 h TWA)	Examples
Rigid, biopersistent nanofibres for which effects similar to those of asbestos are not excluded	0.01 fibres/cm^3 *	Carbon nanotubes, carbon nanofibres, nanocellulose
Biopersistent granular nanomaterial; density >6000 kg/m^3	20 000 particles/cm^3	Ag, Au, CeO_2, CoO, Fe, Pb, SnO_2
Biopersistent granular nanomaterial; density <6000 kg/m^3, size-range 1-100 nm, and nanofibres for which asbestos-like effects are excluded.	40 000 particles/cm^3	Al_2O_3, SiO_2, TiN, TiO_2, ZnO, nanoclays, dendrimers, polystyrene

*) The value is identical to the benchmark exposure limit (BEL) for fibrous nanomaterials proposed by the British Standards Institute (BSI) (BSI 2007).

9. RISK ASSESSMENT AND MANAGEMENT OF NANOMATERIALS AT WORKPLACES

Workplaces should identify whether they use products containing nanomaterials at the same time as they carry out workplace risk assessments for other chemicals. For the first tier assessment (screening the potential exposure sources and level) Control Banding (CB) methods can be used. For detailed exposure assessments, contacting experts of occupational hygiene is recommended.

The workplace risk assessment of nanomaterials may follow the chart below (Figure 1). The first step (tier) is to find out if the nanomaterials/nanoproducts are used at the workplace. The second step is to determine whether the workers are exposed to nanomaterials. The tasks and processes should be evaluated. Workers who use nanomaterials/nanoproducts are included in the exposure register. The products containing nanomaterials should also be notified in the exposure register. The third step is to evaluate the level of exposure and risk to nanomaterials and to check the efficiency of risk management measures. The fourth step is to consider health monitoring of the workers. Construction workers' medical surveillance is recommended to all workers working in the construction industry. Special health monitoring is recommended in a case, when the risk level has been evaluated to be high for NP. Risk assessment and management can be carried out by an occupational hygienist or other expert.

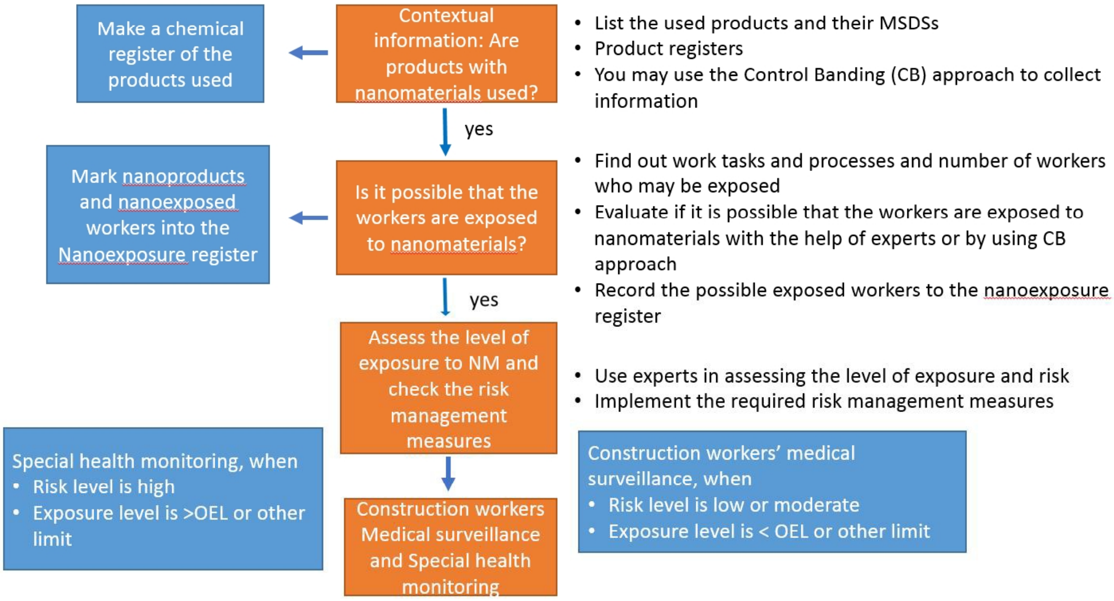

Figure 1. Flow chart of risk assessment and health monitoring procedure in construction work.

Nanomaterials should be considered a group of chemicals at the workplace. As regards those workers who are potentially exposed to nanomaterials, the **employer** should follow a precautionary approach with regard to nanomaterials' risk prevention. This approach should include at least the following:

- Identification of processes and activities in which possible exposure to nanomaterials may occur
- Checking the Material Safety Data Sheets (MSDS) of the products and the information on NPs
- Determining the physical state of the nanomaterials, such as dust, powder, spray, or droplets
- Ensuring that engineering controls are checked and that they work efficiently
- Ensuring that personal protective equipment (PPE) is available and that it is used and handled correctly
- Minimising the number of workers potentially at risk and the duration of exposure to nanomaterials
- Following the recommendations for measuring exposure to NPs.
- Training workers in the use of nanomaterials and good practices at work
- Keeping a record of workers that may be exposed to nanomaterials (see paragraph "Exposure registry")
- Conducting at least the normal medical surveillance of construction workers, paying special attention to potential NP exposure

Workers should remember to:

- Handle nanomaterials according to instructions (of MSDS or equivalent)
- Take part in the training that the employer offers and follow instructions
- Practice good housekeeping at sites where NP release from products is possible
- Clean up engineered nanomaterial contamination using:
    - a dedicated, approved HEPA vacuum, the filtration effectiveness of which has been verified (Note: Consider possible pyrophoric hazards associated with vacuuming up NPs)
    - wet wiping
    - other facility-approved methods that do not involve dry sweeping or the use of compressed air

Remember: In the construction sector, exposure to different types of dusts, fibres, solvents and other chemicals may be very high. The potential health effects induced by these agents are in most cases likely to cause much higher risks than exposure to nanomaterials. In risk assessments, all possible types of exposure must be taken into account and nanomaterial should thus be considered one exposure component among all the others!

9.1 Control Banding approach

A Control Banding (CB) approach can be used to evaluate risk levels at workplaces. Many different CBtools are available for screening the risk level at a working site (Brouwer 2012, EU-OSHA 2013). One of these is the Stoffenmanager Nanotool, which is applicable in many construction sector activities. Stoffenmanager Nano is easy to use and is freely available on the website (https://stoffenmanager.nl/Default.aspx). Stoffenmanager Nano can be used for assessing risk priority levels and the need for risk management measures at construction sites. The Scaffold project is developing a CB tool especially for the construction sector (http://www.scaffold.eu-vri.eu/).

9.2 Adhering to hierarchy of control in risk management

Risk management measures should follow the **hierarchy of control** (Figure 2). Elimination and substitution are at the top of this hierarchy. However, the NPs used in the products have probably been chosen because of their unique properties, so elimination is not possible. Substitution of the nanomaterial by a less hazardous nanomaterial should be considered, if the material in use is known to be harmful. Moreover, the form of the used product may affect potential exposure; for example, dry powder could be replaced with slurry to reduce the risk to workers.

The next option is the implementation of enclosures and engineering controls (e.g. local exhaust ventilation, isolation measures, and dust collection systems). Common controls used in the nanotechnology field include fume hoods, biological safety cabinets, glove box isolators, glove bags, and directional laminar flow booths. Water sprays may reduce respirable dust concentrations generated from processes such as machining; for example, cutting and grinding.

Administrative controls address, for example, the education and training of workers on issues related to nanomaterials, their hazards and good work practices in their handling, and the selection and use of PPE (e.g., clothing, gloves, and respirators). The use of PPE should be the last choice in controlling exposure. The special recommendations for the construction industry can be found from other documents of the EU-Scaffold project (http://www.scaffold.eu-vri.eu/). In order to identify the workers exposed to nanomaterials and the relationships between exposure and health effects, and to rule them out, establishing an exposure registry is highly recommended.

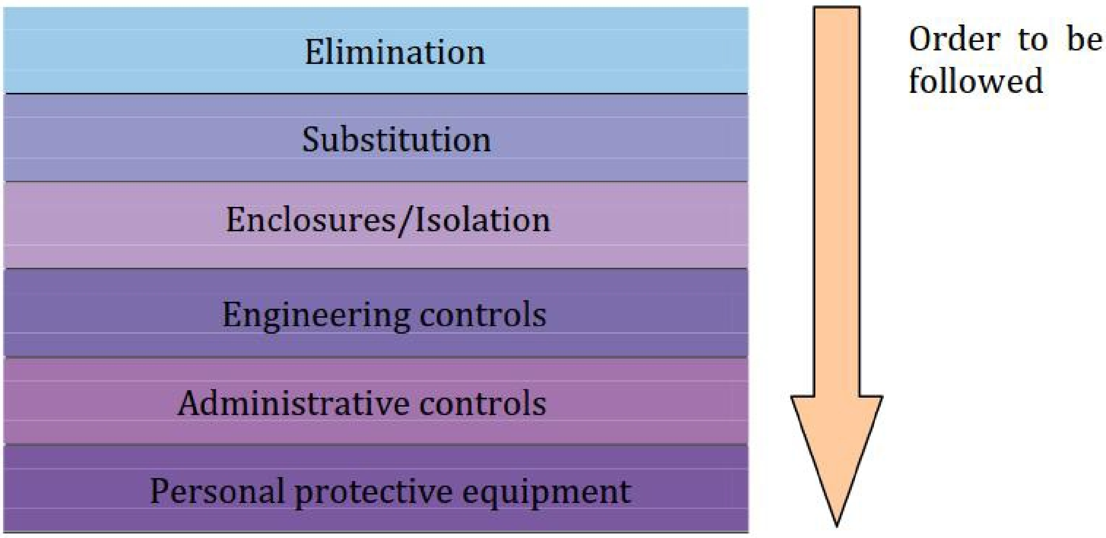

Figure 2. Hierarchy of control (ISO/TS 12901-1:2012)

10. EXPOSURE AND HEALTH MONITORING OF WORKERS EXPOSED TO NANOMATERIALS

10.1 Keeping records of potential nanoparticle exposure

It is recommended that employers keep a record of all workers who might be exposed to nanomaterials. The products containing nanomaterials should also be included in the register.
The aim of the nanoexposure registry is

- for the employer and by the occupational health care unit to identify possibly exposed workers

- that the employer (or occupational health services) has an opportunity to evaluate the exposure level of the workers, and possibly also the symptoms (sentinel events by surveillance) of exposure
- to improve the exposure estimates of nanomaterials in order to focus risk management methods effectively

This exposure register is a personal registry, but further conclusions or studies can be made anonymously using job codes or activity codes. In the construction industry, it may be difficult to distinguish the health effect (and exposure) of nanomaterials from other dominant conventional exposures, for example, ultra-fine and inhalable dust, and quartz. Because of this, the use of the register in epidemiological studies is still secondary. Its main use is its focus on risk management. If registers are planned for use in epidemiological studies in the future, it would be reasonable to use combined company registers that are based on multidimensional job-activity exposure models.

The nanoexposure register model is created in an Excel format and is based on data on the company, product, worker, and exposure (Figure 3). The data can be extracted from the NECID-database if this has been used in exposure assessments. NECID is a database for NP air exposure data developed by a working group of Perosh Institutes (IFA, TNO, NRCWE, HSL, INRS, FIOH, INSHT and CIOP). Its aim is the harmonized and uniform storing of NP exposure and contextual information data and it will facilitate the comparing and sharing of the data in the future (Fransman, Pelzer et al. 2012).However, the nanoexposure register can also be used as a separate register. The company or health care unit should uphold the register. An example of the register is included as an attachment file.

For more information about nano exposure registers, please see the Scaffold report entitled "Exposure register model for construction industry" (http://scaffold.eu-vri.eu/filehandler.ashx?file=13717).

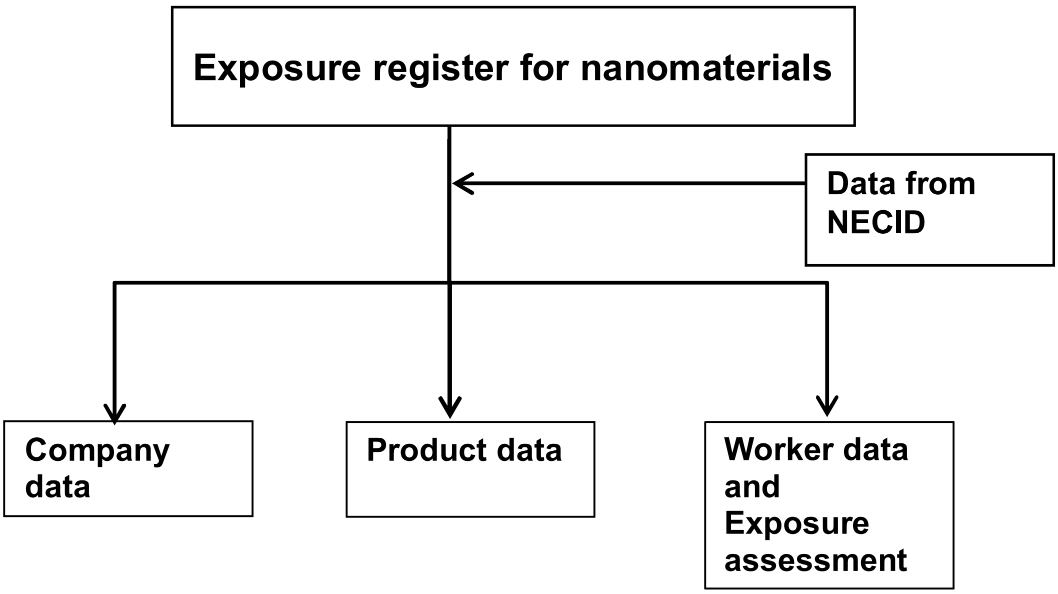

Figure 3. Structure of the nanoexposure register model

10.2 Detecting changes in the health status of workers exposed to nanomaterials

Health surveillance and medical screening offer important means for assessing the health of exposed workers and can be used to identify adverse health outcomes resulting from exposure. Typically, medical screening and health surveillance are used in circumstances in which the health effects of the substances are reasonably well known. Scientific knowledge about the health effects of most nanomaterials is limited. No biomarkers specific to NPs exposure which may predict a possible occupational disease have been identified, nor have medical tests been established to investigate the specific effects of nanomaterials.

At the moment, opinions and recommendations on how to assess the health of exposed workers differ. The available scientific data has been examined, and different experts have given their recommendations. Below, the conclusions and recommendation of NIOSH and the Health Council of the Netherlands are presented. Other countries such as Germany, France, and the United Kingdom have discussed or are discussing the potential use of exposure registries and health monitoring systems, as well as epidemiological and toxicological research. As the field of nanoscience is in a highly dynamic state, with many questions still to be answered regarding the potential health risks of nanomaterials, it is anticipated that different kind of recommendations will be made in the next few years.

10.3 Recommendations of NIOSH and Health Council of the Netherlands

Most of the information on the health effects of nanomaterials has been limited to a few types of NPs, such as titanium dioxide and carbon nanotubes (CNT). Indeed, NIOSH has recommended exposure limits for these two nanomaterials (NIOSH 2013, NIOSH 2011). Moreover, NIOSH has published recommendations for the **medical surveillance and screening of workers who are occupationally exposed to CNT or carbon nanofibres (CNF)** (NIOSH 2013). This NIOSH document states that the toxicological evidence on CNT/CNF is now advanced enough to make specific recommendations for the medical surveillance and screening of exposed workers. That is, the strong evidence for pulmonary fibrosis from animal studies and the fact that this effect can be detected by medical tests is the basis for NIOSH-specific medical screening recommendations. **NIOSH recommends controlling exposure and other risk management practices in addition to medical surveillance. This involves the education and training of workers and the use of PPE (e.g., respirators, clothing, and gloves).**

Workers who would receive the greatest benefit from medical screening are a) workers exposed to concentrations of CNT or CNF in excess of the NIOSH REL (recommended exposure limit), which is 1 $\mu g/m^3$ elemental carbon as an 8-hr TWA, and b) workers in areas or jobs that have been qualitatively determined as having the potential for intermittent elevated airborne concentrations to CNT or CNF. Workers are at risk of being exposed when they are involved in the transfer, weighing, blending, or mixing of bulk CNT or CNF, or the cutting or grinding of composite materials containing CNT or CNF, or when they work in areas where such activities are carried out by others (NIOSH 2013).

The person assigned to carrying out the medical surveillance programme should be a qualified healthcare professional who is informed and has knowledge of potential workplace exposures, the routes of exposure, and the potential health effects related to CNT and CNF. The recommendations for the medical screening of workers exposed to CNT or CNF are:

- An initial evaluation, consisting of occupational and medical history conducted by a qualified health professional, with an emphasis on the respiratory system
- A physical examination with an emphasis on the respiratory system
- A spirometry test
- A baseline chest X-ray
- Other examinations or medical tests deemed appropriate by the responsible health-care professional
    - These should be based on factors such as work-related symptoms noted at evaluation
    - Results of hazard information (e.g. toxicity information) and exposure
- Periodic evaluations
    - Periodic analysis of the medical screening data collected at a workplace by an epidemiologist or other specialist

NIOSH does not recommend specific medical screenings for workers potentially exposed to other NPs, because there is currently insufficient scientific and medical evidence on engineered nanomaterials. The current recommendations are as follows:

- Take prudent measures to control exposure to engineered NPs
- Conduct hazard surveillance as the basis for implementing controls
- Continue the use of established medical surveillance approaches.

However, if NPs are composed of a chemical or bulk material for which medical screening recommendations exist, these same screening recommendations are also applicable to workers exposed to engineered NPs (NIOSH 2009).

The Health Council of the Netherlands (2012) recommends setting up exposure registries for all insoluble NPs and for solid materials in which NPs are incorporated. The exposure registry would concern all companies and institutions that use NPs. The Committee has taken the view that there is no point in setting up separate medical surveillance for nanoworkers. However, passive surveillance is recommended. In the Netherlands, national health registries are designed for the continuous input of disease data. These systems cover a great range of possible health effects and are capable of providing valuable information concerning both short- and long-term health effects. The Committee describes how it is essential to link existing health data from the registries to the new data in exposure registries. The aim is to generate the data needed to determine whether there is an association between exposure to nanomaterials and certain health effects, or to disprove the existence of any such association.

11. RECOMMENDATIONS FOR THE MONITORING OF WORKERS' EXPOSURE TO NANOMATERIALS IN THE CONSTRUCTION INDUSTRY

Occupational health services should carry out surveillance of the work environment and surveillance of workers' health (ILO 1985). Surveillance of the work environment should include, for example, the identification and evaluation of environmental factors that may affect workers' health, and an assessment of hygienic conditions and organizational factors.

It is not always possible to prevent the hazardous exposure of workers with technical procedures. Therefore, blind trust should not be placed in technical control measures.

Surveillance should include all the assessments necessary to protect the health of workers (ILO 1985):

- health assessments before assignment to specific tasks that may involve a health risk,
- health assessments at periodic intervals in employment that involves exposure to a particular health hazard,
- health assessment on return to work after an extended absence due to health reasons, for the purposes of determining possible occupational causes, recommending appropriate action to protect the worker and determining the worker's suitability for the job, and his/her needs for assignment and rehabilitation, and
- health assessments on and after the termination of assignments involving hazards that may cause or contribute to future health impairment.

In the construction industry, health surveillance practices vary between different countries, and may be mandatory, required by national regulation, or voluntary. The interval between periodic examinations varies from 1 to 5 years, depending on exposures and the age of the worker. Construction work involves several types of health risk. Typically, a periodic health examination should include:

- careful documentation of work history, occupation, tasks, exposures, medical history, diseases, and symptoms
- a clinical examination and information
- a hearing test (noise)
- lung function measurements, spirometry (dusts, gases etc.)
- a chest X-ray (fibrogenic dusts)
- additional examinations if needed (depending on exposures and symptoms)
- worker feedback
- feedback on work ability to employer

The following recommendations are given for workplaces in the construction industry in which workers are exposed to nanomaterials, dusts and other substances that may cause adverse health effects:

- Identify the used product and the potential exposure sources, and take measures to control exposure
- Conduct risk assessment by using, for example, a Control Banding method
- Implement required engineering controls and other required risk management measures
- For workers exposed to nanomaterials, establish a nanoexposure registry toenable the assessment of the level of exposure and the determination of the exposure-disease (health effect) association in the future
- **Continue applying established medical surveillance approaches to construction workers (periodic health examination from 1 to 5 years)**
- **For workers likely to be exposed to nanomaterials and if the evaluated risk level is high (for example nanotubes or fibres are handled and exposure occurs), include regular the follow-up examinations, focusing on respiratory (and cardiovascular) systems.**

12. REFERENCES

1) Alenius H, Catalan J, Lindberg H, Norppa H, Palomäki J, Savolainen K (2014). Nanomaterials and human health. In: Vogel U et al (Eds) Handbook of nanosafety. Measurement, exposure and toxicology. Academic Press
2) Brouwer D (2012). Control Banding Approaches for Nanomaterials. Ann Occup Hyg 56: 506-514.
3) BSI (2007). Nanotechnologies – Part 2. Guide to safe handling and disposal of manufactured nanomaterials. PD 6699-2:2007. British Standards Institute. Available at: http://www3.imperial.ac.uk/pls/portallive/docs/1/34683696.PDF
4) DFG (2013). Nanomaterials. Commission for the investigation of health hazards of chemical compounds in the work area. Deutsche Forschungsgemeinschaft. Wiley-VCH Verlag GmbH & Co. KgaA. http://www.dfg.de/download/pdf/dfg_im_profil/gremien/senat/arbeitsstoffe/nanomaterials.pdf
5) Donaldson K, Poland CA. (2013) Pulmonary toxicity of carbon nanotubes and asbestos – Similarities and differences. Adv Drug Del Rev 65:2078-2086.
6) Elvin G. Nanotechnology for Green Building, Green Technology Forum, 2007. http://esonn.fr/esonn2010/xlectures/mangematin/Nano_Green_Building55ex.pd
7) EU (2011) Commission's Recommendation of 18 October 2011 on the definition of nanomaterial, OJ L275, pp. 38-40.Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:275:0038:0040:EN:PDF
8) European Agency for Safety and Health at Work (EU-OSHA). e-Fact 72. Tools for the management of nanomaterials in the workplace and prevention measures. 2013. Available at: https://osha.europa.eu/en/publications/e-facts/e-fact-72-tools-for-the-management-of-nanomaterials-in-the-workplace-and-prevention-measures
9) FIOH (2013) Teollisesti tuotettujen nanomateriaalien tavoitetasoperustelumuistio [Target levels for engineered nanomaterials]. Työterveyslaitos. (*in Finnish*)
10) Franchini M and Mannucci PM (2011). Thrombogenicity and cardiovascular effects of ambient air pollution. Blood 118:2405-2412.
11) Fransman, W., I. Pelzer, W. Stöppelmann, D. Brouwer, I. Koponen, D. Bard, O. Witschger, A. Zugasti, E. Jankowska, A. Säämänen and M. Berges (2012). Development of Nano Exposure and Contextual Information Database (NECID) (abstract for poster presentation). International Congress on Safety of Engineerwed Nanoparticles and Nanotechnologies, 28-31 October 2012. SENN2012. Helsinki.
12) Grosse Y, Loomis D et al. (2014). Carcinogenicity of fluoro-edenite, silicon carbide fibres and whiskers, and carbon nanotubes. Lancet Oncol. 15:1424-1428.
13) Health Council of the Netherlands (2012). Working with nanoparticles: Exposure registry and health monitoring. The Hague: Health Council of the Netherlands, publication no. 2012/31E. Available at: http://www.gezondheidsraad.nl/en/publications/healthy-working-conditions/results/taxonomy%3A398
14) IARC (2010). Carbon black, titanium dioxide, and talc. IARC monographs on the evaluation of carcinogenic risks to humans. IARC Monographs, Volume 93. Lyon, World Health Organization, International Agency for Research on Cancer. Available at: http://monographs.iarc.fr/ENG/Monographs/vol93/mono93.pdf
15) IFA (2014). Criteria for assessment of the effectiveness of protective measures. Available at: http://www.dguv.de/ifa/Fachinfos/Nanopartikel-am-Arbeitsplatz/Beurteilung-von-Schutzmaßnahmen/index-2.jsp (sited 17.2.2014)

16) International Labour Organisation (ILO), Convention No. 161 and Recommendation No. 171, 1985.
17) FIOH (2013). Nanosafety in Europe 2015-2025: Towards Safe and Sustainable Nanomaterials and Nanotechnology Innovations. Eds. Savolainen K. et al. Available at: http://www.ttl.fi/en/publications/electronic_publications/nanosafety_in_europe_2015-2025/pages/default.aspx
18) Napierska D, Thomassen LCJ, Lison D, Martens JA, Hoet PH (2010).The nanosilica hazard: another variable entity. Particle and Fibre Toxicology 7:39.
19) NIOSH (2009). Current Intelligence Bulleting 60. Interim Guidance for Medical Screening and Hazard Surveillance of Workers Potentially Exposed to Engineered Nanoparticles. Publication no. 2009-116. Available at: http://www.cdc.gov/niosh/docs/2009-116/
20) NIOSH (2011). Current Intelligence Bulletin 63. Occupational exposure to titanium dioxide. Available at: http://www.cdc.gov/niosh/docs/2011-160/pdfs/2011-160.pdf
21) NIOSH (2013). Current Intelligence Bulletin 65. Occupational exposure to carbon nanotubes and nanofibers. Cincinnati, OH: Department of Health and Human Services, Centers for Disease Control and Prevention. National Institute of Occupational Safety and Health. Publication no. 2013-145. Available at: http://www.cdc.gov/niosh/docs/2013-145
22) Savolainen K, Pylkkänen L, Norppa H, Falck K, Lindberg H, Tuomi T, Vippola M, Alenius H, Hämeri K, Koivisto J, Brouwer D, Mark D, Bard D, Berges M, Jankowska E, Posniak M, Farmer P, Singh R, Krombach F, Bihari P, Kasper G, Seipenbusch M (2010). Nanotechnologies, engineered nanomaterials and occupational health and safety-A review. Safety Science 48: 957-963.
23) Schulte PA, Murashov V et al. (2010). Occupational exposure limits for nanomaterials: state of the art. J Nanopart Res 12: 1971–1987.
24) SER (2012). Provisional nano reference values for engineered nanomaterials. Advisory report 12/01. The Netherlands. Social and Economic Council. http://www.ser.nl/~/media/Files/Internet/Talen/Engels/2012/2012_01/2012_01.ashx
25) SER (2012). Working with nanoparticles: Exposure registry and health monitoring. Health Council of Netherlands 2012. http://www.gezondheidsraad.nl/sites/default/files/Engineerednanoparticles201231E.pdf
26) van Broekhuizen F and van Broekhuizen P (2009). Nano-products in the European Construction Industry. State of the Art 2009. Executive Summary. Available at: http://www.efbww.org/pdfs/Nano%20-%20final%20report%20ok.pdf
27) van Broekhuizen P, Reijnders L (2012).Building blocks for a precautionary approach to the use of nanomaterials: positions taken by trade unions and environmental NGOs in the European nanotechnologies' debate. Risk Anal 3(10):1646-1657.
28) Weichenthal S (2012). Selected physiological effects of ultrafine particles in acute cardiovascular morbidity. Environ Res 115:26-36.

Further reading on safe use of nanomaterials:
https://osha.europa.eu/en/publications/literature_reviews/workplace_exposure_to_nanoparticles

13. LIST OF TABLES AND FIGURES

14. LIST OF APPENDIXES

Appendix 1. Scheme of the Nanoexposure register model. Information marked with an asterisk is compulsory data.

Sheet 1. **Company data**	**Sheet 2.** **Product data**	**Sheet 3. Worker data, measurement data and exposure assessment**	
		worker data	**measurement data and exposure assessment**
*Company name ***N***	*Industrial sector ***N*** (NACE-code)	*Name of the worker	Sampling date ***N***
Site address ***N***	*Product row number	*Social security number	Location name ***N***
Type of construction (free text)	*Product trade name ***N***	Occupation (free text)	Unit of measurement ***N***
*Industrial sector ***N*** (NACE code and text)	*Product form ***N***	*Job codes (ISCO code and text) ***N***	Personal or static sample ***N***
Remarks	* Used amount and unit ***N***	*Product row number	Background: measured NP concentration ***N***
	*Used MNP (OECD list) ***N***	*Job tasks, activity codes ***N***	Activity or task: measured NP concentration ***N***
	*Used MNP (OECD list) ***N***	*Duration of the task ***N***	Activity-Background: calculated ***N***
	*Used MNP (OECD list) ***N***	*Frequency of the task	Work day: calculated NP concentration / 8h
	Remarks	*Date when the worker started to use MNP	Assess exposure class (high, moderate, low)
		Date when the worker use of MNP has ended	Used OELs or other limit values
		Control measures (free text)	Remarks

APPENDIX 2. Exposure register model for construction industry employers. Separately collected data in Excel format.

SHEET1: COMPANY INFORMATION

NECID*	NECID		NECID*		
Company name	**Site address**	**Type of construction (free text)**	**Industrial sector (NACE code)**		**Remarks**
			code	**text**	

copy corresponding NACE code and text from the link (available in EU-languages)

options:
http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=NACE_REV2&StrLanguageCode=EN&IntPcKey=&StrLayoutCode=HIERARCHIC

* minimum information needed
NECID= data can exported from NECID into the Excel format

SHEET 2: PRODUCT INFORMATION

*	*	NECID*	NECID*	NECID *	NECID *	NECID *	
Industrial sector (NACE-code)[1]	**Product row number[1]**	**Product trade name**	**Product form**	**Used amount and unit**	**Used MNP (OECD list)**	**Used MNP (OECD list)**	**Remarks (free text, e.g. name of the other MNP)**
	1						
	2						
	3						
use the same codes as in Company information sheet	add more numbered rows if needed		choose from the dropdown list **options:** liquid power solid object fibers paste		choose from the dropdown list **options:** Fullerenes (C60) Single-walled carbon nanotubes (SWCNTs) Multi-walled carbon nanotubes (MWCNTs) Silver nanoparticles Iron nanoparticles Titanium dioxide Aluminium oxide Cerium oxide Zinc oxide Silicon dioxide Dendrimers Nanoclays Gold nanoparticles mixture of nanoparticles Other	add if several MNP used, add more columns if needed and choose options from the dropdown list as in previous column	

* minimum information needed
[1] If NECID database is used the register is a one-sheet register including all the fields and no links (NACE-code and product row number) are needed
NECID= data can be exported from NECID into the Excel format

SHEET 3: WORKER AND MEASUREMENT DATA AND EXPOSURE ASSESSMENT

WORKER DATA

*	*		NECID*		*	NECID*		NECID *	*	*		
Name of the worker	Social security number	Occupation (free text)	Job codes (choose ISCO code and text from the list)		Product row number	Job tasks, activity codes (choose from the dropdown list)		Duration of the task	Frequency of the task	Date when the worker started to use MNP	Date when the worker use of MNP has ended	Control measures (free text)
			code	text		code	text					
			copy corresponding ISCO code and text from the link http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=CL_ISCO08&StrLanguageCode=EN&IntPcKey=&StrLayoutCode=HIERARCHIC			**	**	**	**			

* minimum information needed

NECID= data can be exported from NECID into the Excel format

[1] If NECID database is used the register is a one-sheet register including all the fields and no link (product row number) is needed

**Choose from the dropdown list (options presented in Table 4 and 5 in page 16). If several job tasks per person needed, insert them in different lines.

SHEET 3 continues:

MEASUREMENT DATA AND EXPOSURE ASSESMENT

NECID	NECID	NECID	NECID	NECID	NECID	NECID				
Sampling date	**Location name**	**Unit of measurement**	**Personal or static sample**	**Background**	**Activity or task**	**Activity-Background**	**Work day**	**Assess exposure class (high, moderate, low)**	**Used OELs or other limit values**	**Remarks**
				measured NP concentration	**measured NP concentration**	**calculated from the 2 previous columns**	**calculated NP concentration / 8h**			
	work area where the activity takes place	choose from the dropdown list **options:** µg/m3 number/cm3 other	choose from the dropdown list					**		

**Assessment of exposure class: high=workday conc. > OEL and background;
moderate= workday conc. ≤ OEL and background;
low= workday conc. << OEL and background

NECID= data can be exported from NECID into the Excel format