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Development of a real-time information and monitoring system to support the risk assessment of engineered nanomaterials (ENMs) under REACH

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Deliverable

DB1a. Report on the determinants of exposure and exposure scenarios over NMs Life Cycle

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List of acronyms

AC:	Article Category
CES:	Contributing Exposure Scenarios
ECHA:	European Chemicals Agency
EHS:	Environmental, Health and Safety
ENM:	Engineering Nanomaterial
ERC:	Environmental Release Category
ERC:	Environmental Release Categories
ES:	Exposure Scenario
GES:	Generic Exposure Scenarios
IU:	Identified Uses
LEV:	Local Exhaust Ventilation
NM:	Nanomaterial
NOAA:	Nano-Objects and their Agglomerates and Aggregates
OC:	Operative Conditions
PC:	Chemical Product Category
PEC:	Predicted Environmental Concentration
PNEC:	Predicted No Effect Concentration
PPE:	Personal Protective Equipment
PROC:	Process Category
RA:	Risk Assessment
REACH:	Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals
RMM:	Risk management measures
RMMs:	Risk Management Measures
SD:	Source Domain
SU:	Sector of Use category

Summary

Present deliverable compiles the information to develop generic exposure scenarios including information on the conditions of use and risk management measures, according to REACH. It is focused on families of nanomaterials selected based on the global production volume, exposure potential and available information. For each of these nanomaterials, the most relevant uses have been identified and then a use mapping is generated. Use will serve as the basis for the creation of the generic exposure scenarios for hazard/risk characterisation for nanomaterials according to REACH.

Sources compiled in action A3 will be analysed and gathered to group relevant activities according with the likelihood of exposure. In general, there is a current lack of data on the release rate of nanoparticles from conventional sources, since most of studies focused on the quantification of the ENMs in occupational settings through the inhalation route of exposure, being the environmental and consumer exposures widely unidentified.

The results from the measurement campaigns analysed showed that there was variable evidence of exposure to the ENMs depending on variables relying on intrinsic characteristics of the ENM and process-related properties, such as operative conditions or RMMs available. All these factors can increase or reduce the exposure potential for the same ENM analysed, independently of the concentration levels reached at the source or workplace.

In the specific case of the ENMs, an evident lack of knowledge exists regarding the characteristics of the process and risk controls applied at industrial scale. At this stage, the activities to be developed within the action will cover this lack of knowledge by generating a complete library of exposure scenarios. The inventory is key to support the proper use of measured data on a regulatory basis. Both exposure scenarios and environmental release categories (ERC) are key elements in the characterization of the risk characterisation ratios (RCRs).

Table of Contents

1. Scope and goal of the deliverable 5
2. Introduction 5
3. Exposure Scenarios under REACH 6
3.1. Potential of Exposure 8
4. Procedure for the identification of ES 9
4.1. Evaluation of the determinants of exposure 9
4.1.1. ENM-related determinants of exposure 13
4.1.2. Scenario-related determinants of exposure 17
4.1.3. Environmental determinants of exposure 22
4.1.4. Other determinants of exposure 26
5. Identification and cuantification of the main sources of exposure 27
5.1. Use Descriptor system 27
5.2. Mapping of uses of relevant ENMs 28
5.2.1. Mapping of uses of Silver NPs 28
5.2.2. Mapping of uses of Zinc Oxide 36
5.2.3. Mapping of uses of Silicon Dioxide 38
5.2.4. Mapping of uses of Titanium Dioxide 41
5.2.5. Mapping of uses of Cerium Dioxide 47
5.2.6. Mapping of uses of Calcium Carbonate 51
5.2.7. Mapping of uses of Carbon Nanotubes 54
5.2.8. Mapping of uses of Graphene 60
5.2.9. Mapping of uses of Fullerenes 62
5.2.10. Mapping of uses of Nanocelluloses 64
5.3. Main sources and levels of exposure 66
6. Conclusions 72
7. Annex 73
A1. Descriptors by Process Categories 73
A2. Descriptors by Sectors of Use 76
A3. Descriptors by Chemical Product Category 76
A4. Descriptors by Environmental Release Categories 77

1. Scope and goal of the deliverable

The first implementation action defined under the scope of the project is dedicated to the development of a web based library of exposure scenarios and measured data on exposure and release of Engineered NanoMaterials (ENMs).

The main goal of the action is to develop an on-line inventory of exposure scenarios and exposure monitoring data to facilitate the access to information and promote the use of the data generated within the project under the risk assessment process established by REACH.

With the aim of obtaining a consistent identification of a well-established set of exposure scenarios and refined release factors and Environmental Release Categories (ERC), it was carried out a throughout study of the main factors affecting the release or exposure to ENMs, shown in this deliverable "**DB1a. Report on the determinants of exposure and exposure scenarios over NMs Life Cycle**".

In order to fulfil this purpose, a tiered approach was followed, developing firstly a complete inventory of data on the concentration levels of ENMs in industrial settings and relevant environmental compartments. This inventory is based on the information compiled and analysed within action A3, and will be updated and refined as new data become available, either from the monitoring station, as well as retrieved from the literature.

The second step is to develop a library of exposure scenarios based on REACH information containing reliable data on the measured levels of exposure, Risk Management Measures (RMMs) and Operative Conditions that may influence the potential exposure to ENMs in the workplace and the potential release to the environment, such as physicochemical properties of ENMs, rate/volume of production, descriptors of the physical worksite (e.g. size or age), geographic location, meteorological factors (i.e. temperature and humidity), as well as other inherent characteristics of the activities conducted in a specific process involving the production and/or use of ENMs.

The ultimate purpose of this information is to provide a complete description of the specific determinants of exposure across the life cycle stages of the ENMs for the definition of nanospecific ERCs, and whose results will be analysed in depth and exposed in "**DB1b. Report on nano-specific release factors and environmental release categories**" which is used in turn to support the derivation of the Predicted Environmental Concentration (PEC) of ENMs.

2. Introduction

According with the ECHA Guidance on information requirements and chemical safety assessment, as well as the RIPoN 3 "Specific Advice on Exposure Assessment and Hazard/Risk Characterisation for Nanomaterials under REACH" [1], published by the European Commission on July 2011, the risk assessment process under REACH is based on the estimation of the exposure on the basis of the operational conditions (OC) and risk management measures (RMM) that conform the specific exposure scenario of a substance.

[1] Specific Advice on Exposure Assessment and Hazard/Risk Characterisation for Nanomaterials under REACH (RIP-oN 3), Final Project Report, Aitken, R.A, Bassan, A., Friedrichs, S., Hankin, S.M., Hansen, S.F., Holmqvist, J., Peters, S.A.K., Poland, C.A., Tran, C.L., RNC/RIP-oN3/FPR/1/FINAL, 07 July 2011

In the specific case of the ENMs, an evident lack of knowledge exists regarding the characteristics of the process and risk controls applied at industrial scale. At this stage, the activities to be developed within the action will cover this lack of knowledge by generating a complete library of exposure scenarios (ES).

On the other hand, the estimation of the exposure under REACH can be conducted using recommended Tier 1 models such as ECETOC TRA[2] or ART tool[3] based on release factors calibrated with bulk substances. In activities involving the use of ENMs the use of these approaches can result inappropriate. At this stage, the refined or new release factors will improve the accuracy of current models used for risk assessment purposes in the context of REACH.

The action has been considered highly relevant, being key to support the proper use of measured data on a regulatory basis. Both exposure scenarios (ES) and environmental release categories (ERC) are key elements in the characterization of the risk characterisation ratios (RCRs).

3. Exposure Scenarios under REACH

Based on REACH regulation, an **exposure scenario** is a **set of information describing the conditions under which the risks associated with the identified use(s) of a substance, either in a pure state or in a mixture, can be controlled,** including the operational conditions and necessary risk management measures contained in it.

The Operational Conditions (OCs) comprise any action, use of tool or parameter present during manufacture or use of a substance that as a side effect might have an impact on exposure of humans and/or the environment (for example the duration and frequency of use or the amount used, the process temperature or the pH).

On the other hand, the Risk Management Measures (RMMs) include by definition any action, use of tool, change of parameter state introduced during manufacture or use of a substance in order to prevent, control, or reduce exposure of humans and/or the environment. Examples of RMMs are Local Exhaust Ventilation (LEV) systems such as capture hoods or an any kind of Personal Protective Equipment (PPE), such as gloves or masks, as well as wastewater and gas treatment.

Exposure Scenarios (ES) are hence one of the main tools for the chemical safety assessment and the related communication in the supply chains under REACH. The term Exposure Scenario stands for the combination of operative conditions and risk management measures applied during specific activities such the synthesis of a nanomaterial or the maintenance of equipment. In the ES description should be included manufacture and all identified uses of a substance and all risks related to consumers, workers and the environment, arising from those uses,

[2]https://www.google.es/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&ved=0ahUKEwie2ZDS8O7QAhULuRQKHd4jBkYQjBAIKTAC&url=http%3A%2F%2Fwww.ecetoc.org%2Fwp-content%2Fuploads%2F2014%2F08%2FECETOC-TR-114-ECETOC-TRA-v3-Background-rationale-for-the-improvements.pdf&usg=AFQjCNFt7ksEwQ_vswHygxOPUdyyp5Xjog&cad=rja

[3] http://www.hse.gov.uk/msd/uld/art/try.htm

considering the use of the substance on its own, in a mixture or in an article as defined by the identified uses.

Therefore, first of all, all the stages in the life cycle of a nanomaterial (Figure 1) considering the four basics steps have been defined: manufacture, formulation, use (industrial, professional and consumer) and article service life (industrial and consumer).

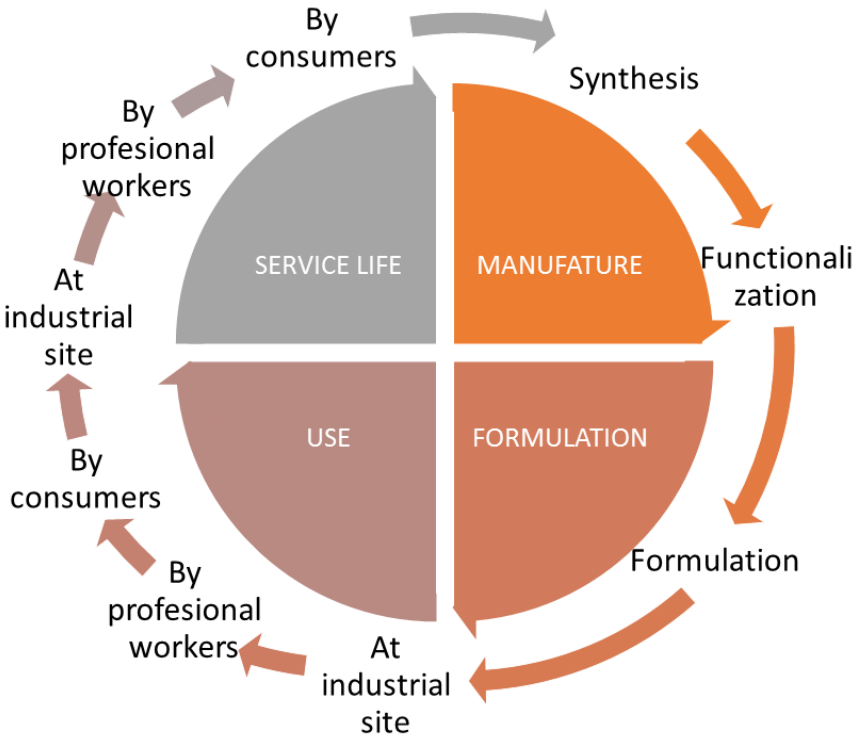

Figure 1: Life Cycle stages of an ENM.

The life cycle of ENMs starts with the synthesis and if required, functionalization, depending on the NM and the properties desired. The manufacture is followed by the formulation stage during which the material is transferred and mixed with other substances in order to be placed on the market as a mixture to then be used at industrials sites, by professional workers or by consumers.

Occupational exposure at these two first stages is mainly a result of airborne nanoparticles that are released during the handling of the ENM at the different formulation processes or during maintenance and cleaning of equipment and facilities. Airborne or waterborne nanoparticles (in wastewater principally) may then find their way out into the environment.

The next stage of the life cycle of nanoparticles deals with their applications. In the case of industrial sites, nanomaterials are processed and become part of an article, either for further transformation at industrial sites by professional workers, or as a final product to be placed in the market. Exposure at these stages may be a result of ''detached'' nanoparticles during the processing or use of the mixtures.

Last stage is related with the service life of the articles. This includes professional processing of semi-finished articles, use or maintenance of the article by professional workers or consumers

and waste. Weathering of products is the main cause of exposure in this case although it should be noted that compared to the levels of exposure during previous stages, potential of exposure is significantly lower.

3.1. Potential of Exposure

A comprehensive assessment of the potential exposure to nanomaterials should include all life cycle stages and take into account both human and environmental exposure. Human exposure refers to both the occupational exposure which occurs at workplaces during the performance of the job duties, the consumer exposure during the use of an article containing ENMs or the exposure due urban, rural or environmental settings.

The exposure potential depends, apart from the amount of the ENM in direct contact, on the nanomaterial itself (its chemical potential toxicology), the time and amount of contact (i.e. the dose), the route of exposure, the protective equipment wore, the layout of the facilities, RMMs in place, etc. Particular attention should be paid during the performance of auxiliary handling processes, and maintenance or cleaning, where due to the nature of the ENMs the exposure is more likely to be high.

In the case of service life, nanomaterials have become part of an article and as a result exposure is mainly related to the weathering of the end-products, thus in general the exposure potential is lower in all compartments, although dermal and oral consumer exposures increase depending on the use of the final product (e.g. alimentary uses, cosmetics or textile).

On the other hand, environmental exposure refers to the amount of ENMs being released to the environment. Industrial activities (synthesis and use) that involve the handling of ENMs, including the equipment maintenance processes, are very likely to release ENMs, airborne or waterborne.

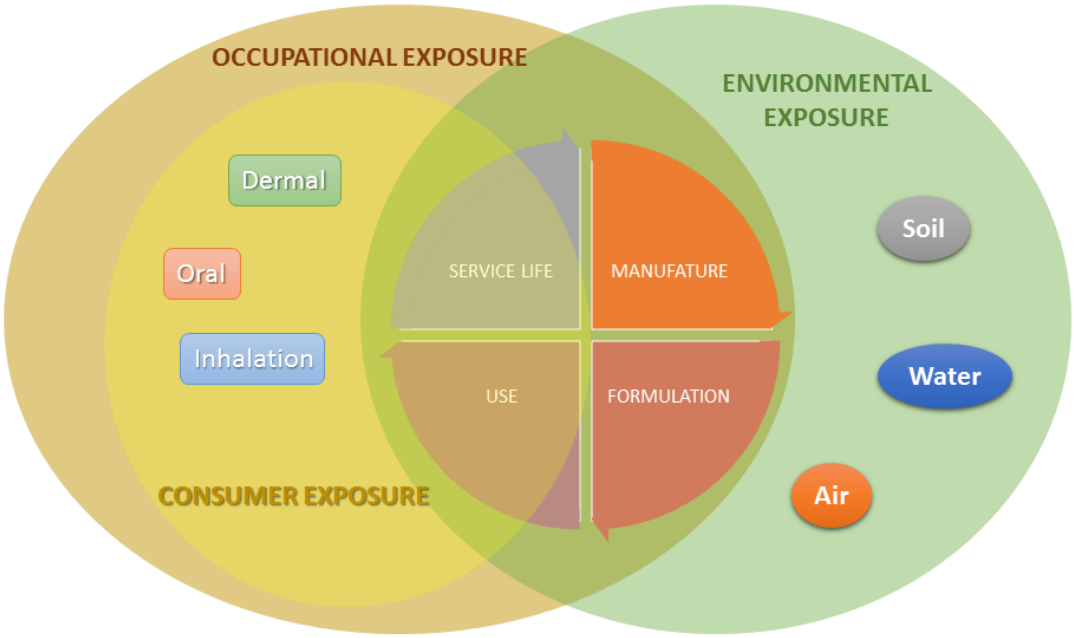

Figure 2: Potential routes and scenarios for exposure depending on the life cycle stage of the ENM.

Therefore, the identification and categorization of the routes and the potential of exposure at the different stages and scenarios in which there are ENMs involved will help to detect and prevent a potential risk for the health and the environment.

In general, apart from the stage of the life cycle, some of the determinants of exposure are related with:

- Type of product
- Rate/volume of production
- Company demographics (profitability, public/private)
- Descriptors of physical worksite (size, age)
- Geographic location (seasonal factors, urban/rural surroundings)
- H&S program
- Indoor/outdoor environmental factors: Temperature, humidity, wind velocity or ventilation characteristics (capture velocity, face velocity, distance…)
- Process factors: voltage/amperage, temperature…
- Material factors: base, size, amount…
- Work practices: distance from source, flow direction (worker-source)

All these factors will be further identified and analysed in the following sections.

4. Procedure for the identification of ES

The definition of the ES is based on a top-down approach in which in first place the different stages of the life cycle of the nanomaterials are identified. Based on the stages and depending on the application range of each ENM a series of identified uses is derived. Subsequently, a use mapping process is performed on each identified use, with the aim of identify those activities and processes that could pose risk for the up or downstream users or the environment.

Once defined the uses, the **Generic Exposure Scenarios (GES)** are generated. The GESs describe the operational conditions and RMMs present. For example, in occupational exposure, OCs (e.g. exposure duration, substance concentration) and RMMs (e.g. local exhaust ventilation, gloves) are described for workers involved into each handling activity and are expressed as Contributing Scenarios. On the other hand, for environmental exposure, OCs (e.g. river flow rate, STP size, and working days) and RMMs (e.g. oil skimmer, carbon filter) are described as part of “Specific ERCs” (spERC).

Finally, the exposure is estimated for each identified use. The exposure estimation is the input for the risk characterisation.

4.1. Evaluation of the determinants of exposure

There are many factors affecting the release of an ENM and thus the human or environmental exposure to it. The first of all is the chemical nature of the ENM itself. Many physicochemical properties can be designed into the material and changed by synthesis and formulation, so it will not be possible to establish classes of nanomaterials based on composition or a limited set of structural properties. Therefore, it may be important to establish a set of physical, chemical

and in vitro screening methodologies that determine the bio-interaction class of materials based on physicochemical properties, and on the functional performance of the nanomaterials that indicate the relative chemical reactivity, surface charge, solubility, and surface composition.

The ENM nature has been divided in different categories[4] upon its main families, characteristics and uses. These are:

- *Oxides*: Mainly **TiO_2, ZnO, CeO_2, Fe_3O_4, MnO_2, SiO_2**, among others. Because these materials are used in such diverse applications, it is difficult to assess the potential hot spots in applications and disposal. Precipitated materials processes are likely to predominate for synthesis (sol-gel, chemical precipitation, arc), although applications research priorities may also include applications where the ENMs may be released from the matrix, dispersed applications (sunscreens) or application formulations with human exposure potential (paints).

- *Metals*: such as **Ag, Co, Ni, Fe, Pt, Rd, Al, Cu, etc.** The most common applications of nanometals are catalysis (Cobalt, Nickel, Iron for carbon nanomaterial synthesis or Platinum, Palladium, Rhodium as catalytic converters) or antimicrobial applications (Silver), but also for medical diagnostics (Gold), or uses as propellant and in electronics (Aluminum, Copper).

  Metals used in embedded catalytic applications present usually low risk for human or environmental exposure though their life cycle. However, nanosilver and nanocopper may have risk as ecotoxins in the disposal of waste. Most metal nanoparticles will form oxides and thus they are a potential hot spot regarding exposure.

- *Carbon based*: It includes different species such as **Nanotubes (single-, double- or multi-wall), Fullerenes, Carbon Black or Graphene**, among others. Within these general categories there is great diversity among size, structure, physical aggregation forms, and residual species associated with the carbon. Most of the discussion focused on CNTs/nanofibers and fullerenes because these are produced in relatively large quantities by industry, and in small scales in university and research settings, and have many applications.

  In many applications, these carbon based ENMs are part of a composite material, strongly bound to the host polymer. In some materials (such as single- and double-walled nanotubes) the carbon materials can form large aggregates and do not provide a ready source of nanoparticles on their own. Alternatively, in applications like drug delivery, the carbon materials are treated to remain suspended in water and resist aggregation.

  On the other hand, although the intrinsic toxicity of carbon was recognized as being low, factors as particle size (small being more toxic) and contamination with other materials (metal contamination of CNTs), and certain characteristics of size and shape may enhance toxicity.

[4] ICON (International Council on Nanotechnology), 2008, Towards predicting Nano-Bio interactions: An International Assessment of Nanotechnology Environment, Health and Safety Research Needs, ICON no.4, May, 1, 2008

- *Semiconductors*: **Quantum Dots (QDs**), also known as Fluorescent crystalline semiconductor NPs, are being developed for use in optoelectronic applications such as light-emitting diode (LED) displays, and solar cells; and inks and paints for identification or brand protection.

  QDs have shown the ability to dissolve and release their constituent components into solution over time. Therefore, any assessment of potential hazard from QD exposure should distinguish between QDs whose constituents are known to be highly toxic, such as Cadmium, and those with lower intrinsic toxicity, such as Selenium or Zinc.

- *Macromolecules*: includes **branched polymeric organic molecules,** focusing on NMs generally engineered from organic molecules to have a precise size, shape, and surface functionality, such as **dendrimers, dendrons, and dendrigrafts of various generations, hyperbranched polymers and nanoengineered classical polymers**. Naturally occurring macromolecules such as DNA constructs, peptides/peptoids/ proteins, carbohydrates etc. are not considered to be relevant for exposure in this case.

  The greatest exposure potential to free ENMs of this kind will occur with synthetic techniques and applications in which the materials are aerosolized. There is less of a concern around potential for high exposure at the end of life of products containing macromolecules because of their high propensity for degradation in the environment. The greatest concern addressed was the difficulty in removing these materials at waste treatment plants.

- *Self-assembled NMs*: they are composed of even smaller nanoscale building blocks such as **lipids and metal oxide nanoparticles**, and may include modifying components such as **surfactants, inorganic materials, and organic molecules**. Examples include nanoemulsions, lattices, hollow spheres, tubes, and capsules.

  Regarding the exposure potential, lipid assemblies have high potential for environmental transformation. They may bind non-specifically to entities in the environment that would change their shape, chemistry, and propensity for environmental transport. Inaccurate assembly could permit inappropriate systemic transport; e.g., across the blood-brain barrier, or through the environment.

The Table 1 collects the average values for the most relevant physicochemical properties of the NMs for risk assessment purposes, including information on key values identified in the literature for the most relevant ENMs used in the industry. The results for each endpoint may change on the basis of the experimental methods and conditions used.

Table 1. Available Information on relevant physicochemical properties

NANOMATERIAL	Size distribution	Z Potential	Specific surface area	Physical appearance	Density
	nm	mV	m^2/g		g/cm^3
OXIDES					
SiO_2	10 - 90	+30 (pH <7); -17 (pH >7)	100	n-podwer	0.05-1.5
TiO_2	20- 60	+ 40 (pH <7); -50 (pH >7)	50	n-podwer	130

ZnO	20 -90	+ 12 (pH <7); -15(pH >7)	19	n-podwer	>100
Al_2O_3	5 - 150	31.2 ±0.41	> 40	n-podwer	> 10
Fe_2O_3	8 – 20	49.2 ± 0.42	>40	n-podwer	> 100
Fe_3O_4	8 - 20		>40	n-podwer	> 100
ZrO_2	10-50	+ 20 (pH <7); -30 (pH >7)	45-130	n-podwer	20
CeO_2	4-20	+ 36 (pH <7); -15 (pH >7)	152	aqueous suspension	40
$CaCO_3$	90	+ 10 (pH <7); -20 (pH >7)	70	n-podwer	0.4
CuO	40	HV	> 10	n-podwer	0,8
METALS					
Gold	20	HV	HV	n-podwer	HV
Silver	20 - 95	HV	HV	n-podwer	HV
Platinum	20- 80	HV	HV	n-podwer	HV
Palladium	30 - 45	HV	HV	n-podwer	HV
Copper	40	HV	15	n-podwer	HV
Iron	30-60	HV	>12	n-podwer	>0.5
Titanium	10 - 40	HV		n-podwer	HV
Nickel	50	HV	10	n-podwer	HV
Cobalt	200-300	HV	15	n-podwer (wires)	HV
Aluminium	HV	HV	24	n-podwer	HV
CARBON BASED					
Fullerenes	HV	HV		n-podwer	HV
SWCNTs	Diameter: ca. 1,4 nm; Length: > 10 µm	HV		n-podwer	HV
MWCNTS	5-20 nm; Inner diameter: 2-6 nm; Length: 1-10 µm	HV		n-podwer	0,15-0,35
Carbon black	13 nm	HV	550	n-podwer	120 g/L
Graphene flakes	HV	HV		n-podwer	HV
Graphite	HV	HV		n-podwer	HV
Nanodiamonds	4	-50 ± 5	290-360	n-podwer	0,69
SEMICONDUCTORS					
Quantum dots	2 - 3	HV	HV	Aqueous suspension	HV
Dendrimers	HV	HV		n-podwer	HV
Nanoclays	1 nm thick	(-18.5 ± 0.4 mV, pH 4.5; (-36.8±1.3) mV, pH 7.2; (-39.1±0.6) mV, pH 9.0	71	n-podwer	HV
Nanocellulose	HV	HV		n-podwer	HV
Nanozeolites	HV	HV	HV	n-podwer	HV

HV: High Value with respect to the non-nano material.

Exposure to these ENMs over their life cycle—manufacture, use and disposal—present different issues for safety assessment and are largely unknown. The highest risk areas in the life of these materials are in the handling of powders: bagging and unbagging, maintaining pyrolysis reactors, cleaning bagging houses, and accidental spilling. anything that disrupts the normal process, maintenance, cleaning, vacuuming, and failure of PPE is considered able to generate high exposure as well.

Following manufacture, transport, and transfer from transport vessels into a subsequent product may potentially generate high exposure. Carbon nanomaterials are produced in a multitude of different forms for subsequent use. Examples include powders of various sizes, pressed fibres, suspensions in fluids, and dry coatings on surfaces. Waste disposal and unintended use were also considered to be potentially high-exposure scenarios.

On the other hand, little is known with respect to human and environmental exposure through release during degradation of products or during the transportation of raw materials and products. The environmental fate of consumer products is also poorly understood. There is very little information on the behaviour of released nanoparticles in waste water or groundwater.

Unexpected hot spots for exposure potential may occur as well from degradation by-products of these materials resulting from temperature, oxidative, or photochemical degradation, during service life or disposal of the final product.

4.1.1. ENM-related determinants of exposure

The physico-chemical characteristics of the product are a key factor for the emission potential of ENMs in the environment, for example the **physical state** of the nanoparticle or product containing ENPs. The nature of the exposure varies significantly from powder to liquid to solid, and it is determined by different factors.

For *powders*, the emission potential is dominated by the level of dustiness of the material handled, understood as the intrinsic potential of a determined ENP to become airborne. Powder form may be supplied as fine powders (high dustiness), agglomerated powders (medium dustiness), and pellet-type solids (low dustiness). Much of the ENMs in powder form can be assigned to one of these powder categories, covering fine dust and/or extremely dusty forms. Several parameters will influence the mass of the dust liberated from a ENM being handled, including the amount and type of energy applied in the process, the time frame of the working procedure, moisture content of the powder or air humidity during the handling, and electrostatic and surface properties of the powder. As a general rule, ENPs in dry powder form present the greatest potential for airborne exposure, since they are easily aerosolized with very small amounts of applied energy.

Though the handling of ENPs suspended in a *liquid* is preferable, processes like spraying, agitation and accidental spills can increase the exposure level, forming aerosols or splashes when processed under input of mechanical energy. Furthermore, right after it is created, the liquid aerosol starts evaporating, exposing the worker in the vicinity also to ENPs in dry form, if evaporation is complete, or liquid vapors. Evaporation rates are affected by factors like the liquid's vapor pressure, which is in turn affected by the ambient temperature and concentration

of vapor in the room (relative humidity). Other key parameters related to the emission potential in liquid dispersions include the concentration of the solute, the diameter of dispersed particles and viscosity. Other processes, like stirring (which is energetic enough to produce "waves" on the liquid surface and, then, aerosolization) or sonication (that uses ultrasound to break up agglomerates) can release ENPs. However, in manufacturing plants, stirring occurs in closed vessels[6].

The least exposure potential occurs for *ENPs incorporated into a solid matrix*, which can occur in a composite of ENPs and a polymer, in a surface coating or simply mixing ENPs into the bulk of a solid. A key driver for the fraction of substance that may be released into the environment or is available for direct exposure of humans (oral or skin contact) is the ratio of surface to volume. Similarly, the product specifications, i.e. concentration/ percentage of the nanoparticles in a mixture or article, may be directly linked to the release rate of ENPs in workplace environments. Concerning the life cycle of the material, the major risk of exposure takes place during manufacture. ENPs can also be released when energy is applied to the material (cutting, drilling or simply weathering) or during end-of-life treatments. At the present time, very little is known about the disposal of products containing ENPs.

Thus, concerning the ENM specie, the intrinsic properties of the material[5] will be determinant to evaluate the risk of the exposure to it. Some of these properties are listed in Table 2.

Table 2: Determinants for exposure regarding the ENMs properties according to ECHA registration dossier.

SIZE AND SHAPE	
Particle size (Primary/Secondary)	Information on primary particle size, size range and number size distribution. The same information would be needed for secondary particles (e.g. agglomerates / aggregates) if present. A particle's size can contribute in several ways to its toxicity, including the deposition pattern of the particle in the respiratory system, the likelihood of the particle to penetrate the skin, and particle mobility once it enters the body[6].
Physical form and morphology	Information on the physical form and crystalline phase/shape. The information should indicate whether the ENM is present in a particle-, tube-, rod-/shape, crystal or amorphous form, and whether it is in free particulate form or in an agglomerated/ aggregated state as well as whether the preparation is in the form of a powder, solution, suspension or dispersion. Dry powders present the higher risk of exposure, followed by ENMs suspended in a liquid and ENPs incorporated in a solid matrix.
Zeta potential	It is an important parameter related to ENPs long term stability or aggregation in a dispersion, and it is associated with the surface charge of nanoparticles in solution (colloids). Particles with high Z-Pot (<-30mV or >+30mV) typically have a high degree of stability, since they repel each other and resist aggregation in

[5] European Food Safety Authority, "Scientific Opinion on Guidance on the risk assessment of the application of nanoscience and nanotechnologies in the food and feed chain," EFSA Journal 2011;9(5):2140 (36 pp.)

[6] Ellenbecker, M. J., Su-Jung Tsai C., Exposure Assessment and Safety Consideration for Working with Engineered Nanoparticles, Wiley (2015)

	solution. Dispersions with a low zeta potential value will eventually aggregate due to Van Der Waal inter-particle attractions.
Particle and mass concentration	Information on concentration in terms of particle number and particle mass per volume when in dispersion and per mass when as dry powder. The important point to keep in mind is that very small releases of nanometer-sized material on a mass basis will correspond to very large numbers of particles. It affects the agglomeration rate and degree via particle-to-particle interactions.
STATE OF DISPERSION	
State of the substance at 20 °C and 101,3 kPa	Information on the physical state (gaseous, liquid or solid), form (e.g. compact, crystalline, fibre, filaments, flakes, particulates, paste, pellets, powder, or viscous liquid etc.), colour, odour, and other remarks related to physical state, appearance or colour at standard conditions.
Agglomeration/aggregation state	Related with the crystalline and to the total specific surface area, which is either less than the sum of the surface areas of the primary particles structure (when primary particles aggregate), or the total surface area does not differ appreciable from the sum of specific surface areas of primary particles (in the case of agglomerates). It is affected by particle concentration, zeta potential/surface charge, shape, hydrophobicity etc.
Crystalline phase /Crystallite and grain size	It can influence on other characteristics such as dispersion properties, isoelectric point and oxidant capacity.
Dustiness	Information on dustiness of powder products such as spices, creams and soup powders.
PHYSICO-CHEMICAL PROPERTIES	
Chemical composition/ identity	Information on chemical composition of the ENM including purity, nature of any impurities, coatings or surface moieties, encapsulating materials, processing chemicals, dispersing agents and/or other formulates e.g. stabilisers.
Melting/freezing/boiling point	Change of state point values (ºC) as measured, corrected to standard pressure, except where the boiling point has been determined at specified reduced pressures, rate of temperature increase if available, decomposition or sublimation temperature (if applicable), measurement uncertainty if available, and if testing is waived, the reasons for waiving must be documented.
pH	pH of aqueous suspension.
Viscosity	Information on viscosity of liquid dispersions.
Density and pour density	Information on density/porosity of unformulated ENM and pour density.
Vapour pressure	Measured value of the vapour pressure for at least two temperatures (ºC), estimate of the vapour pressure at 20 or 25 ºC (if not measured at these temperatures). If a transition (change of state, decomposition) is observed, the nature of change and temperature at which change occurs should be noted.
Water solubility	Information about water solubility in (mg/L) at given temperature (ºC), pH value and concentration of test substance.
Flammability	Indicate lower and upper explosion limits in % volume and burning time.
Explosive properties	The mechanical sensitivity test according to UN Test Series 3a and 3b must be done and documented if UN Test Series 1 or 2 give a positive result.

Self-ignition temperature	Value or the range of the auto-ignition temperature, for liquids/gases: observations (e.g. decomposition with air, reactions with moisture, etc.)
Oxidising properties	indicate the results of the spontaneous ignition test, the mean pressure rise time for the test substance, the mean pressure rise time for the reference substance(s) and interpretation of results.
Stability in organic solvents and identity of relevant degradation products	Only required if stability of the substance is considered to be critical.
Dissociation constant	Concentration of the substance, test results as pKa-value(s), temperature of the test medium (ºC).
Viscosity	Viscosity value and unit according to the used test method, preferred units are m Pa·s (for dynamic viscosity) and mm2/s (for static viscosity) but other units are also accepted; each measured value should be accompanied with temperature (in °C). Usually two values are needed. Preferably one value is measured in app. 20°C and another in app. 20°C higher temperature. Two determinations of viscosity should be measured for each temperature. For non-Newtonian liquids, the results obtained are preferred in the form of flow curves, which should be interpreted. Individual and mean values should be provided at each temperature.
Radical formation potential	Components of particles have the potential to generate free radicals in the lung environment and thereby cause oxidative stress; which is an important mechanism leading to inflammation.
SURFACE AREA AND POROSITY	
Specific surface area	Information on specific surface area of the ENM. Both the total aerosol surface area and particle surface-to-volume ratio increase significantly as particles move from the micrometer- to the nanometer-size range. As a consequence, toxic effects that are more closely related to surface area than particle's size may become more relevant. Much of the ENP toxicity literature seems to correlate adverse effect with particle surface area, implying that surface area may be a good indicator of exposure.
Porosity	Including information on skeletal density (ρS), porosity, total pore volume (TOPV), and pore size distribution.
SURFACE PROPERTIES	
Surface chemistry	It consists of a wide variety of properties that govern the way in which particles interact with the environment. It includes solubility, catalytic properties, surface charge, surface adsorption and desorption of molecules from solution, etc. Most of these properties are functions of the atomic or molecular composition of the surface and the physical surface structure. It can change in a variety of ways, particularly through the adsorption or coating of the particles with proteins or other species from the biological fluid surrounding them[7].
Surface charge	Approximated by the zeta potential of the ENM.
Chemical reactivity/catalytic activity	Information on relevant chemical reactivity or catalytic activity of the ENM and of any surface coating of the ENM.
Photocatalytic activity	Information on photocatalytic activity of relevant materials used in packaging, coatings, and printing inks and internal reactions.

[7] Powers, K. W. *et al*, Research Strategies for Safety Evaluation of Nanomaterials. Part VI. - Characterization of Nanoscale Particles for Toxicological Evaluation, Toxicol. Sci. 90, 296-303 (2006)

Redox potential	Information on redox potential. Conditions under which redox potential was measured need to be documented.
Solubility and partition properties	Information on solubility of the ENM in relevant solvents and their partitioning between aqueous and organic phase.

Therefore, the substance emission potential can be considered specific of each ENM. For ENMs in powder form, the emission potential will be determined by the dustiness of the material. In the case of colloidal dispersions containing ENPs, the concentration of the solute, diameter of dispersed ENPs, and viscosity of the mixture are a key parameters influencing the emission potential, and thus the risk of exposure.

4.1.2. Scenario-related determinants of exposure

In general, the form and amount of ENMs released are determined by the activity emission potential and the substance emission potential[8, 9]. Both variables are essential when assessing exposure to ENMs. The activity emission potential is commonly related with the amount of ENM used, energy applied in the process and level of containment. The substance emission potential can be considered specific of each ENM and its intrinsic physico-chemical properties. Finally, a tertiary nanoparticle aerosol source may originate from the use or processing of products or intermediates containing nanoparticles. Examples of this source are spraying of particulate suspensions or the compounding of nanopowders with polymers. The likelihood of release of the original particles is extremely low according with recent studies. Therefore, large matrix bound particles are expected.

A classification of the main sources of exposure has been proposed[8], identifying four **Source Domains (SD)**, each associated with a life cycle stages of the nanoparticles; from production, downstream use, to end-of-life treatments. These are:

SD1. Point source or fugitive emissions;
SD2. Handling and transfer of bulk manufactured nanomaterial powders with relatively low energy;
SD3. Dispersion of either (liquid) intermediates containing highly concentrated (>25%) nanoparticles or application of (relatively low concentrated <5%) ready-to-use products;
SD4. Activities resulting in fracturing and abrasion of manufactured ENMs-enabled end-products at work sites such as abrasion, manual sanding, grinding, drilling or cutting.

The **first source domain (SD1)** considers the release of nanoparticles during the **production phase (synthesis)** before harvesting the bulk material. Examples under this source domain include emissions from a reactor during a flame spray pyrolysis synthesis, leaks through seals and connections, and incidental releases. The types of nanoparticles released during this process include both process-generated nanoparticles and engineered nanoparticles.

[8] Schneider, T. et al, Conceptual model for assessment of inhalation exposure to manufactured nanoparticles, J Expo Sci Environ Epidemiol 2011, 460-63
[9] Fransman W, et al, Development of a Mechanistic Model for the Advanced REACH Tool (ART), 2009, TNO Report V8667, The Netherlands

The **second source domain (SD2)** include activities related with the **production of nanoparticles and downstream processes** including using nanoparticles for the manufacturing of nano-enabled products. Examples of such activities include the collection and harvesting of ENMs, packing or weighting, among other activities.

The **third source domain (SD3)** include activities related with the **preparation** of highly concentrated (>25%) nanoparticles dispersions, or the **application** of products containing relatively low concentrations of nanoparticles (<5%) such as nano-enabled products for personal care; for example, spraying of personal care products that can generate large fractions of aerosols in the nanometer range after condensation.

Finally, the **fourth domain (SD4)** includes activities related with **mechanical processes** that may lead to the liberation of nanoparticles from a matrix. As stated previously, nanoparticles embedded in a solid matrix are unlikely to be released during handling, although it is possible that if the matrix is subject to high mechanical and thermal energies, such as when being cut or ground, nanoaerosols may be released. However, the number of research efforts that deliberately investigate release from a solid is still scarce. The particulate material released is most often a mixture of multiple elements, including particle of matrix alone, particles of matrix with the nanomaterial embedded, as well as the nanoparticles fully dissociated from the matrix.

The exposure potential during activity is directly related with the operational conditions implemented in the workplace during the production and downstream use of ENMs. The main operational conditions related with the emission potential include: duration and frequency of exposure, applied amount of ENPs, temperature, containment of the process, and capacity of surroundings. Moreover, the specific RMMs and good industrial hygiene practices implemented to minimise exposure of workers during and after normal operations are also essential in the capacity of release and exposure of the ENMs.

An overview of these parameters and specific issues related with the use of ENMs in occupational settings is provided within Table 3.

Table 3. Main release and exposure influential factors in occupational environments.

PROPERTIES	DESCRIPTION	NANO-SPECIFIC ISSUES
OPERATIONAL CONDITIONS		
Duration and frequency of exposure	Describes the duration and frequency of those activities involving a potential release of ENPs in the life cycle, from production and downstream use, production of nanoproducts, to end-of-life treatments	It is recommended the use of the realistic worst case combination of duration and frequency of use for one worker.
Physical form of the product	Describes the physical state of the ENMs under conventional operations, including powder forms, granules/flakes, liquid dispersion and particle-matrix complexes.	Dustiness (ideally quantitative) is the key parameter for powders and granules/flakes (that may either be firm or crumble emitting dust), together with moisture content and weight fraction of the ENM. In the case of liquids, viscosity is a fundamental determinant. Exposure to ENMs dispersed in

		liquid with low viscosity, which are more inclined to become airborne, results in a higher exposure.
Concentration of substance in mixture or article	Ideally, the percentage of ENM contained in the final product and, if present, encapsulation or treatments applied to the ENM should be indicated.	Determines the possibility and percentage of the release and therefore, the exposure potential. It is a relevant parameter of exposure for all types of products (powders, granules/flakes or liquids).
Amount of ENMs applied	Describes the maximum amount of ENMs used in a determined scenario. In some situations, however, the exposure is related to certain activities (e.g. maintenance and cleaning) more than to the amount handled.	The amount of ENMs is generally low. It is recommended to refer the study to the maximum realistic amount of ENMs used.
Temperature	Describes the temperature of the process. With respect to exposure the most important issue is that volatility is dependent on temperature, mainly in liquid dispersions.	The most important issue is the effect of the temperature on the formation of ENMs from volatile drops generated after the evaporation of nanofluids.
Humidity/Moisture content	Humidity is determinant in the case of solids and powders, since it propitiates agglomeration and aggregation of ENPs. If the ENPs are suspended in water, it is the concentration of vapor in the room.	In high humidity conditions, exposure can be lower due to the big agglomerates formed by the particles, which deposit faster. It affects the evaporation rate of the substance.
Energy applied to the process	Describes the type and level of force applied under normal operational conditions, including motive forces, gravitational, friction, heat, pressure drop and other dispersion forces	Especially during manufacturing, the nanomaterial is moved mechanically at high velocity through the processes. The fraction of aerosolized material can be increased of several orders of magnitude[6]. Pressure drop and friction are of special interest in indoor environments, causing intentional or unintentional release of ENMs.
Capacity of surroundings	The collection of the characteristics of the area where the activity takes place like room volume and ventilation.	It has direct impact on the concentration and dilution of background aerosols in the air. The concentration of background aerosols is an essential factor in the transport and transformation processes of ENMs once released.
Surface contamination and fugitive emissions	Release of deposited contaminants on surrounding surfaces (including worker clothing) due to natural means or general workplace activities (for example moving equipment/vehicles) and unintended and unpredictable leaks from process equipment.	For large rooms and high general ventilation rates, the duration of the activity made little difference to dispersion but not for small poorly ventilated rooms. ?????? Exposures of this type are handled by the strict use of good work practices at the facility.

RISK MANAGEMENT MEASURES		
RMMs and Industrial hygiene practices	Describe the specific types of controls applied on site to limit the release of ENMs, including the use of engineering controls aimed at reducing the release of NPs from specific sources. The use of localized controls in the close proximity of the source is essential.	Good hygiene practices such as cleaning limit the release of deposited ENMs due to natural means or general workplace activities. At the same time, operations like periodical cleaning of the reaction vessels can lead to very high exposure levels due to re-suspension[10].
Containment of the process	Describes the level of containment of the process. The level and means of containment determine the release potential (e.g. closed process equipment/glove box can reach up to 100 % of containment).	There is limited information on the effectiveness levels of conventional containment systems and personal protective equipment against ENMs. Recent sources of evaluation of RMMs are the outcomes from the NanoRisk[11] and NanoReg[12] projects (LIFE12 ENV/ES/000178 and FP7/2007-2013- 310584, respectively)
Localized controls	Risk control measures in close proximity of the source intended to remove emissions (LEV, wet suppression techniques, enclosing hoods, glove boxes/bags).	
Segregation	Isolation of sources from the work environment without containment of the source itself (for example with a separated drying room). Presence of filters and ventilation is taken into account to establish the level of segregation.	
Separation	Referred to providing a worker with a personal enclosure within a work environment (for example air conditioned cabin). Also refers to containing the source in order to reduce emissions (for example with a glove-box).	
Dispersion (dilution)	The state of dispersion of NPs systems refers to the relative number (or mass) of primary particles in a suspending medium in comparison to agglomerates. Outdoor/Indoor work, natural and mechanical ventilation determine the dilution of air contaminants through the room. Room volume and changes per hour are dispersion factors affecting exposure. Slight perturbations in solution properties such as pH, ionic strength, and concentration of molecular constituents can significantly alter the dispersion of nanoparticle systems.	

[10] Methner M. M., Effectiveness of Local Exhaust Ventilation (LEV) in Controlling Engineered Nanomaterial Emissions During Reactor Cleanout Operations, J. Occup. Environ. Hyg., 5, D63-D69 (2008)
[11] Guidance on Recommended Measures and Controls for Mitigating the Risk Posed by Engineered Nanomaterials, http://www.lifenanorisk.eu/index.php/interactive
[12] http://www.nanoreg.eu/media-and-downloads/factsheets-of-nanoreg-output?start=20

Organizational measures and administrative controls	Administrative controls are defined as any activity that do not physically change the work environment but contributes to reduce worker exposure[6], like housekeeping, hygienic and safe work protocols in place, worker training, supervision, etc.	
Personal protection and health evaluation	Efficiency of respiratory and dermal protective equipment (gloves, face protectors, full body dermal protectors, goggles, respirators, etc.), correct replacement, cleaning, monitoring and maintenance of RMMs, etc.	
Waste management measures	Conditions on how the waste (solid liquid or airborne residues) is managed and disposed or recycled	Waste management is also directly related with the environmental protection.

The level and type of **energy applied** in the activity is a key underlying determinant of exposure, being directly related with the source strength. Hence, a better understanding of this factor is essential to estimate the release of ENMs in the indoor environment. In essence, the type of energy applied can be divided into five main classes, including motive forces, gravitational and impaction forces, friction, pressure drop and other dispersion forces, and heat.

Motive forces are primarily related to movement of product or movement of objects contaminated with a product. It excludes motion where friction is caused between bound materials. Gravitational and impaction forces are primarily related to forces during falling and caused by the final impact on surfaces. These three forces are relevant for fugitive emissions in several life cycle stages, including production and downstream use of ENMs.

Frictional forces are primarily caused during an activity where friction between bound materials and collisions induced by friction causes comminution. These forces are considered to be important during operations such as abrasion or drilling within the fourth source domain described previously.

Pressure drop and other **dispersion forces** such as spraying are primarily caused by pressurized sources or other forces/techniques causing intentional or unintentional dispersions of ENMs into the air. These forces are relevant in activities such as the application of dispersions of ENMs using hand spray bottles or pressurized cans.

Finally, there is also evidence that **heat** modifies the exposure in workplaces. Heat energy may be actively applied during the process, or it may also present as a result of a chemical reaction process. This last force is generally determined by e.g., processing temperature (melted solids), voltage, or agitation level.

The **scale of the activity** is relevant in terms of emission potential of bulk materials, however, the influence in the context of ENMs is expect to be limited due to the current production levels. This parameter is commonly expressed in terms of application rate (kg or l/h), amount produced or volume of materials processed per time unit (m^3/h).

It should be noted that much of the factors described previously can be influenced by other aspects such as meteorological conditions or skills of the individual worker. The way the NM is handled, or the performance of activities such as mixing or stirring may be very prone to behaviour, with a direct impact on the release potential of the activity, and therefore the exposure.

4.1.3. Environmental determinants of exposure

The environmental exposure assessment is built upon the following previously performed processes: collection of information on relevant substance properties (physico-chemical characterization, fate as well as (eco-)toxicological properties identification), hazard assessment and mapping of uses.

ENMs are released by anthropogenic activities to the different environmental media (or compartments). In order to properly assess exposure levels, the evaluation of environmental release has to cover all the phases of the life cycle of the material, including discharge into the environment via ENM production, incorporation of the ENM into products, use of products containing the ENM, as well as via sewage treatment plants, waste incineration plants, landfill and recycling. Little is known about the relative importance of these processes[13], though it is plausible that the biggest release in the environment comes from spillages associated to transportation of ENMs from production facilities to manufacturing sites, intentional releases and releases associated with wear and erosion from general use[14].

ENMs are expected to be found in all the environmental media, such that exposure can occur through different routes, schematically shown in Figure 3:

- **Air**: direct release to air occurs during production or product manufacturing, e.g. through open windows when powders are used incautiously, from accidents and spills or from incineration plants.
- **Water**: ENMs emitted to air will deposit on water surface. Moreover, treated or untreated waste water effluents from production facilities, from direct intentional discharge, accidents during transportation and spillage can contaminate aquatic systems and particles in solid wastes can be transported to water by wind or rainwater runoff. However, almost no direct data relevant to the fate and behaviour of ENMs in aquatic ecosystem is currently available[15].
- **Soil**: ENMs emitted in the air will deposit also on land, though it is plausible that they are mainly released to soil through waste stream from production facilities, spillage associated to transportation and intentional release. No data on concentrations of ENPs in real soils are available at present, and the very limited amount of existing data on their transport through solid media indicates that ENPs could be transported into water bodies[15].

[13] Gottschalk, F. et al, The release of engineered nanomaterials to the environment, J. Environ. Monit., 2011, 13, 1145.
[14] Ray, P. C. et al, Toxicity and Environmental Risk of Nanomaterials: Challenges and Future Needs, J. Environ. Sci. Health C, 27, 1-35, 2009.
[15] Brar, S. K. et al, Nanomaterials in the Environment, Published by American Society of Civil Engineers, 2015.

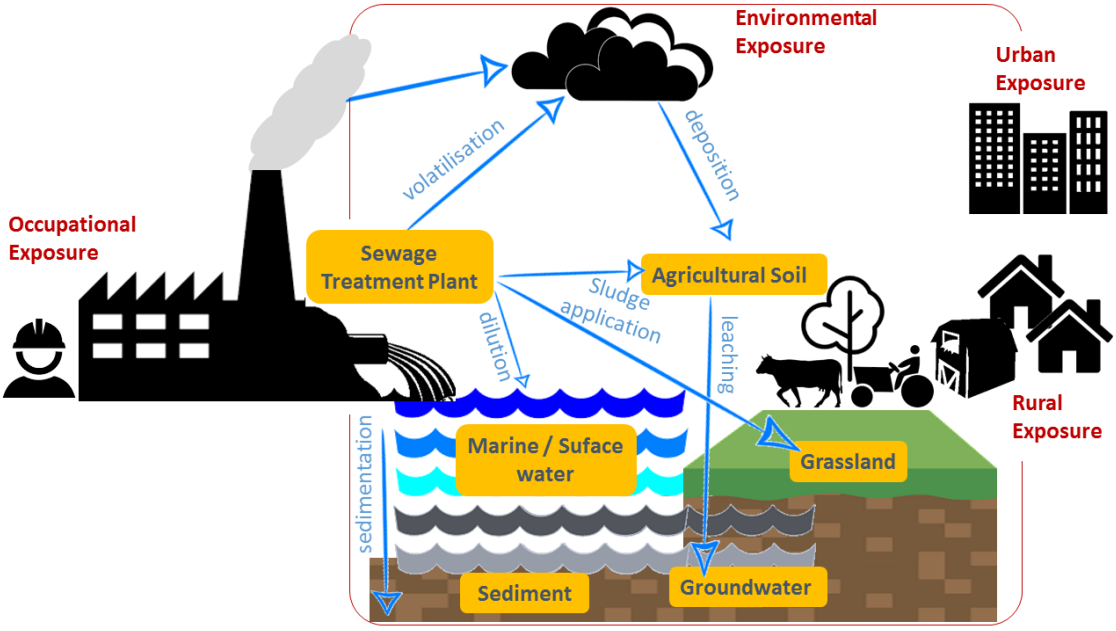

Figure 3: Types of exposures for the scenario related to uses at industrial site.

As in the case of occupational exposure assessment, both the operational conditions and the RMMs determine the levels of exposure to ENMs in the different environmental media. The principal determinants for exposure in the environmental compartments are listed in Table 4.

Table 4. Main release and exposure influential factors in environmental compartments[16].

Properties	DESCRIPTION	NANO-SPECIFIC ISSUES
OPERATIONAL CONDITIONS		
Release rate	An average release rate over the year (kg/day) to wastewater, surface water, air and soil at different scales.	A release assessment covering the whole ENM lifecycle is required (production, incorporation processes, use, waste handling and recycling processes
Tonnage information	Amount used at a typical industrial site (Tonnes/day), in a standard town of 10000 inhabitants or at regional scale for each use (Tonnes/year).	Assessed assuming a generic, representative site. Site-specific assessment might be necessary.
Conditions of use (Design of technical process)	Whether is a fully open or contained processes.	Between an initial release factor to water/air of 100% (fully open system) and an initial release factor of <0.0001% (largely closed system) various levels of release occur in practice.
RISK MANAGEMENT MEASURES		
Onsite Risk Management Measures	Filters, scrubbers, biological or physico-chemical wastewater treatment plants.	Scarce data on efficiency of RMMs at nano-scale.

[16] ECHA Guidance on information requirements and Chemical Safety Assessment, Chapter R.16: Environmental exposure assessment, Version 3.0, February 2016.

Biological Sewage Treatment Plant (STP)	Releases to the environment by water are reduced by degradation, Volatilisation and adsorption on sludge; releases to air may occur, and to agricultural soil will occur if the sludge is applied as fertilisers (leading to a transfer of substance from water to soil and by further transport to crops etc.)	By default, it may be assumed that the releases to water are treated in a Standard Biological Sewage Treatment Plant (STP) before being released to the environment and the STP-sludge is applied to agricultural soil.
Waste treatment operations	Waste incineration (municipal waste incineration, hazardous waste incineration, sewage sludge incineration) and landfilling.	Types of waste treatment techniques are not suitable for all substances.
Frequency of release	Releases of substances can either be continuous or intermittent (less than once per month and for no more than 24 hours).	For widespread uses, intermittent releases cannot be assumed.

RMMs reducing releases to one environmental compartment may increase the releases to other compartments (e.g. wet scrubber collects release to air but may redirect them to water) or to waste.

Once the ENMs are released in the environment, they are free to move across the different media. In order to assess the risk associated with the presence of ENMs in the environment, it is necessary to understand their mobility and the *transport processe*s (sedimentation, dry and wet deposition, aerosolization, soil runoff, etc) that determine their behaviour. These processes are governed by their physico-chemical properties, with **particle size** representing the major influence factor. Nonetheless, also geographical and meteorological parameter can strongly affect the particle concentration in the different compartments. The key factors dominating the transport behaviour of ENMs in the environment are listed in Table 5.

Table 5. Main physico-chemical, geographical and meteorological influential factors for environmental transport behaviour.[17].

Properties	DESCRIPTION	NANO-SPECIFIC ISSUES
ENM's PROPERTIES		
Particle size	Information on primary particle size, size range and number size distribution	It governs the transport properties of the ENM (mass diffusivity, sedimentation velocity, deposition velocity, attachment efficiency).
Physical form	E.g., if it is embedded within a solid matrix, present in liquid form in emulsions or suspensions or used as aerosols that are emitted directly to the air	Fundamental to evaluate release rates. The release of ENM contained in liquids, pastes, creams, powders and aerosol spray is expected to be significant. However, ENM not incorporated strongly into the matrix of larger-particle materials may also be emitted during the use of the solids (mechanical abrasion, aging)[13].
Aggregation state	Homoaggregation is more frequently	Leads to the elimination of NP from water and air by sedimentation and deposition respectively. Can be affected by various factors such as **pH**,

[17] Liu, H. H. and Cohen Y., Multimedia Environmental Distribution of Nanomaterials, Environ. Sci. Technol., 2014, 48 (6), pp 3281–3292

	encountered in laboratory based studies, whereas heteroaggregation occurs widely in natural systems	**temperature**, **surface chemistry**, **presence of ions** in the solution, **viscosity** and polarizability. It also depends on the concentration of NPs.
Sorption	It includes adsorption, absorption and ion exchange, fundamental physical factor in aquatic environment	Plays an important role in altering NM reactivity. Nanomaterials have significant adsorption capacities because of their relatively large surface area and they are able to bind or carry other molecules (dissolved organic matter, surface-active dispersing agent, contaminants and proteins). The physicochemical properties of NMs can be altered by attaching these molecules to the surface. Stability and mobilization of NMs in environmental media can be affected[18].
Dissolubility	The dissolution of sparingly soluble ENMs in the water compartment	It can be the dominant mechanism for removal of particulate ENMs from water[19]. Aqueous solubility of the dissolving species can be affected by various factors such as **pH**, **temperature**, **surface chemistry** and the **presence of ions**.
ATMOSFERICAL FACTORS		
Precipitations intensity	In millimeters per hour (mm/h) over a given duration	Affects wet (air→water, air→soil) deposition and soil runoff.
Wind intensity	Wind speed	Causes soil resuspension (soil→air), affects dry deposition (air→soil, air→water) and aerosolization (water→air).
GEOGRAPHICAL FACTORS		
Interfacial area	Surface of separation between two environmental media	It plays a role in aerosolization (water→air), deposition (air→water, air→soil) and sedimentation (water→soil).
Water currents or wave action	The motion of waves, sea and lakes currents and rivers flow	It causes sediment resuspension in water (soil→water).
Soil properties	Like sil depth, density, type of soil, erodibility, average soil particle size…	Affect soil loss due to runoff.
pH	Acidity or basicity of an aqueous solution	Changes in the pH of the suspension lead to changes in the surface charge density[13]. This may affect stability, aggregation and transport of nanoparticles.
Ionic strength	Measure of the concentration of ions in the solution	It alters the charge screening and, therefore, the range of electrostatic repulsion. In the case of natural waters with sufficiently high ionic strength, ENMs are expected to form agglomerates with diameters exceeding 100 – 1000 nm.
Concentration of organic matter	Natural organic matter (NOM), such as the humic substances found in water,	The presence of NOM affects the state of aggregation of the nanoparticles by forming a charged external interaction with the nanoparticle

[18] Peijnenburg W. J. G. M. et al, A Review of the Properties and Processes Determining the Fate of Engineered Nanomaterials in the Aquatic Environment, Critical Reviews in Environmental Science and Technology, 45 (2015)

[19] Liu, H. H. et al, Simulation Tool for Assessing the Release and Enviromental Distribution of Nanomaterials, Bellstein Journal of Nanotechnology, 15, 938-951 (2015)

	sediment, and soil, is one of the substances capable of interacting with ENPs.	surface that improves the steric stability of the system, hence influencing the mobility of the particles in the environment[20].

In summary, release rates to the different environmental compartments over the entire life cycle of the materials, together with the determinants regulating their transport processes across the different media, are key factors for a correct assessment of the potential impact of ENMs on the environment.

4.1.4. Other determinants of exposure

Exposure assessment can be an iterative process. If the risk characterisation indicates that the applied OCs and RMMs are not adequate to control risks occurring from the manufacture and all identified uses, the exposure assessment may need to be refined.

If the risks are not assessed as being controlled after a first assessment, the assessment may be iterated, either by refining the hazard data (deriving Predicted No Effect Concentrations (PNECs) on the basis of long-term data instead of short-term data for example) or exposure concentrations. The latter may be iterated by improving the release estimation by either refining or **adding more specific RMMs/OCs** or **refining the tonnage** for the use or refining the parameters in the applied release estimation method based on representative onsite data, such as release measurement, which should be linked with the RMMs/OCs.

On the other hand, the exposure estimation may be improved by using representative **measured data** (e.g. environmental concentrations or measured river flow rates) corresponding to OCs/RMMs in place and assigned to the appropriate spatial scale, or using **higher tier exposure** estimation tools; also **improved models/tools** for the estimation of the fate of the substance in a biological STP may be used, always taking into account that their precision against real data is lower.

The refining of the **substance properties** (e.g. degradation rates, partitioning coefficient) considered for the exposure assessment might lead to worst-case results because of limited knowledge of the properties having an impact on fate and distribution of the substance. It might therefore be necessary to refine information related to degradation rates, partitioning coefficients, vapour pressure, water solubility etc.

Alternatively, it can be refined the **characterisation of environmental compartments for site-specific assessment.** Local and regional environments are not actual sites or regions, but standardised environments based on generic parameter. When more specific information is available on the location of release sources, this information can be used to deviate from these default parameters and refine the assessment.

[20] Grillo, R. et al, Engineered nanoparticles and organic matter: A review of the state-of-the-art, Chemosphere, 119, 608-619 (2015)

Also methods can often make use of relevant statistics about the activities that can lead to an exposure, generally drawn from the scientific literature or governmental statistics, such as amount of different food eaten by specific populations, divided by location or age, breathing rates, time spent for different modes of commuting, showering or vacuuming, as well as information on types of residences. Such information can be combined with contaminant concentrations from *ad-hoc* studies or monitoring network to produce estimates of the exposure in the population of interest. These are especially useful in establishing protective standards.

Each of the exposure factors involves humans, either in terms of their characteristics (e.g., body weight) or behaviours (e.g., amount of time spent in a specific location, which affects exposure duration), but they carry a great deal of variability and uncertainty. Consequently, the necessity of continuous refinement of the exposure approach.

5. Identification and cuantification of the main sources of exposure

Exposure is assessed through the estimation of the magnitude, frequency and duration of exposure to an agent, along with the number and characteristics of the population exposed. Ideally, it describes the sources, pathways, routes, and the uncertainties in the assessment.

Risk is a function of exposure and hazard; risks of an adverse outcome are unlikely if exposures are near zero. Thus, the importance of the quantification of the exposure. To calculate the exposure of particular individuals or populations two approaches are used, primarily based on practical considerations:

- **Direct approach:** measures the exposures to pollutants by monitoring the concentrations reaching the respondents. The pollutant concentrations are directly monitored on or within the person through point of contact, biological monitoring, or biomarkers.
- **Indirect approach:** measures the pollutant concentrations in various locations or during specific human activities to predict the exposure distributions within a population. The indirect approach focuses on the pollutant concentrations within microenvironments or activities rather than the concentrations directly reaching the respondents. The measured concentrations are correlated to large-scale activity pattern data.

Especially when determining the exposure of a population rather than individuals, indirect methods can often make use of relevant statistics about the activities that can lead to an exposure. Nevertheless, exposure assessment is a continuous process that is updated as new information and data becomes available.

5.1. Use Descriptor system

The description of the different processes and activities across the life cycle stages of ENMs will give us a better understanding of the release and exposure potential. On this basis, the activities and processes compiled from the literature have been classified following the system of use descriptors published by the European Chemicals Agency (ECHA) in order to standardise the description of the processes and activities identified across the life cycle. This approach, according to the RIPoN 3 "*Specific Advice on Exposure Assessment and Hazard/Risk*

Characterisation for Nanomaterials under REACH" published by the European Commission on July 2011, applies equally well to ENMs as to substances.

The Use Descriptor System is based on **five separate descriptor-lists** which in combination with each other form a brief description of use or an exposure scenario title:

- The **Process Category (PROC)** describes the application techniques or process types defined from an occupational perspective; the PROC, in combination with the operational conditions and risk management measures, is the prime determinant for the level of occupational exposure.
- The **Sector of Use** category (**SU**) describes in which sector of the economy the substance is used. The three main user categories (SU3: industrial; SU21: consumer; SU22: professional) represent the minimum of information needed to describe the sector.
- The **chemical Product Category (PC)** describes in which family of chemical products (substances as such or in mixtures) the substance is contained when it is supplied to end uses (by industrial, professional or consumer users).
- The **Article Category (AC)** describes the type of article into which the substance has eventually been processed.
- The **Environmental Release Category (ERC)** describes the broad conditions of use from an environmental perspective, based on those characteristics that give a first indication of the potential release of the substance to the environment.

For each step in the life cycle, the activities and processes identified in the literature were studied in detail and classified following the use descriptors, enabling the generation of a map of uses for each step in the life cycle.

5.2. Mapping of uses of relevant ENMs

Exposure scenarios are a tool to estimate exposure, dose, and risk. An exposure scenario generally includes facts, data, assumptions and inferences about how the exposure takes place. However, an exhaustive review of every possible exposure scenario for every possible receptor population would not be feasible. Instead, representative examples may be used to formulate scenarios that are appropriate to the assessment of interest, and apply the same or similar data sets and approaches.

In the following Table 5 to Table 14, the main **Identified Uses (IU)** for some of the most used ENMs in the industry, that is **Ag, ZnO, SiO_2, TiO_2, Ce_2O_3, $CaCO_3$, CNTs, Graphene** and **Fullerenes** are listed and sorted upon the Contributing Scenarios (CS), the sector of use during the life cycle of the ENM (Industrial use (I), Professional use (P), Consumer use (C)) and the classification scheme shown in previous section. Taking into account the information available at the moment and aiming to provide a coherent framework that could allow for further refinement, we have based the selection of the IUs on the most widespread uses. However, it should be noted that the application range of the ENMs is remarkably wide and thus different combinations of Use-Descriptors may be required even when application is encompassed in the same IU.

5.2.1. Mapping of uses of Silver NPs

Although traditionally Silver particles have been used in photographic film applications, its antimicrobial properties can be useful for applications related to medicine, sanitary sector, coating of handles and controls etc. Although is mainly used in antimicrobial uses (textiles, wound plasters, anti-odour sportswear, bed mattresses etc.), nanosilver can also provide electrical conductivity to be printed electronic circuits and high reflection rate in the range of thermal-IR which makes it suitable for heat insulation applications.

Table 5: Mapping of uses and use descriptors for the Ag NPs.

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
IU0: SYNTHESIS / FUNCTIONALIZATION														
X								CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3 SU 8 SU 9	-	-	ERC 1
								CS 2	Synthesis	PROC 1				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling	PROC 1 PROC 2 PROC 3				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
IU1. FORMULATION														
	X							CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 10	-	-	ERC 2 ERC 3 ERC 4 ERC 5
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 10 PROC 13 PROC 26				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9 PROC 26				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
IU2. USE IN COATINGS AND PAINTS														

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 5 SU 6a SU 6b SU 10 SU 11 SU 12 SU 13 SU 14 SU 15 SU 17 SU 19	PC 8 PC 9a PC 18	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 8 PC 9a PC 18	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
								CS 3	Application/use (brushing, spraying)	PROC 2 PROC 8a PROC 8b PROC 10 PROC 11 PROC 13				
				X				CS 1	Application/ use	-	SU 21	PC 8 PC 9a PC 18	-	ERC 8a ERC 8d
					X			CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19	-	-	AC1 AC2 AC 3 AC4 AC5 AC6 AC8 AC10 AC13	ERC 2 ERC 3 ERC 4
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14				
								CS 3	Manual cutting, cold rolling or assembly/disassembly of material/article	PROC 21				
								CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 5	Sand and die casting, tapping and casting melted solids, drossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				
								CS 7	Other hot work operations with metals	PROC 25				
						X		CS 1	Application and use	PROC 21 PROC 23	-	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b
							X	CS 1	Use	-	SU 21	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b
IU3. USE IN CLEANING AGENTS														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3	PC 35	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 9 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
								CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 35	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
			X					CS 3	Application/use (brushing, spraying)	PROC 2 PROC 8a PROC 8b PROC 10 PROC 11 PROC 13				
				X				CS 1	Application/ use	-	SU 21	PC 35	-	ERC 8a ERC 8d
IU4. USE IN COMPOSITES AND POLYMER ADDITIVES														
								CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 3	PC 31 PC 32 PC 34	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 10 PROC 13				
		X						CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
								CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 31 PC 32 PC 34	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
			X					CS 3	Application/use	PROC 2 PROC 8a PROC 8b PROC 10 PROC 11 PROC 13				
					X			CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19	-	-	AC1 AC2 AC 3	ERC 2 ERC 3 ERC 4

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14			AC4 AC5 AC6 AC8 AC10 AC13	
								CS 3	Manual cutting, cold rolling or assembly/disassembly of material/article	PROC 21				
								CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				
								CS 5	Sand and die casting, tapping and casting melted solids, drossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				
								CS 7	Other hot work operations with metals	PROC 25				
						X		CS 1	Application and use	PROC 21 PROC 23	-	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b
							X	CS 1	Use	-	SU 21	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b
IU5. USE IN ELECTRONICS COMPONENTS, BATTERIES AND FUEL CELLS														

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3	PC 7 PC 14 PC 0	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 9 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 3	PC 7 PC 14 PC 0	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
								CS 3	Application/use	PROC 2 PROC 8a PROC 8b PROC 13				
				X				CS 1	Application/ use	-	SU 21	PC 7 PC 14 PC 0	-	ERC 8a ERC 8d
					X			CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19	-	-	AC1 AC2 AC 3	ERC 2 ERC 3 ERC 4
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14				
								CS 3	Manual cutting, cold rolling or assembly/disassembly of material/article	PROC 21				
								CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 5	Sand and die casting, tapping and casting melted solids, drossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				
								CS 7	Other hot work operations with metals	PROC 25				
						X		CS 1	Application and use	PROC 21 PROC 23	-	-	AC1 AC2 AC 3	ERC 10a ERC 10b ERC 11a ERC 11b
							X	CS 1	Use	-	SU 21	-	AC1 AC2 AC 3	ERC 10a ERC 10b ERC 11a ERC 11b
IU6. USE IN COSMETICS														
			X					CS 1	Application/ use	PROC 9 PROC 10 PROC 11 PROC 13	SU 22	PC 39	-	ERC 8b
				X				CS 1	Application/ use	-	SU 21	PC 39	-	ERC 8a ERC 8d
IU7. USE IN MEDICAL TECHNOLOGY														
						X		CS 1	Application and use	PROC 21 PROC 23	SU 22	-	AC2 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b

5.2.2. Mapping of uses of Zinc Oxide

Major uses of ZnO nanoforms are as UV-filter in cosmetics, in varnishes (as UV-filter and self-cleaning agent), ceramics and electronics. Other uses include rubber where it improves toughness, abrasion resistance and prevents UV and bacterial degradation, nanowires for UV nanolasers, liquid crystal displays and solar cells. Nevertheless, cosmetics and paints absorb almost the entire nano-ZnO production volume. Other applications include ceramics, electronics, rubber where it improves the toughness, abrasion resistance and as a protective agent preventing UV and bacterial degradations.

Table 6: Mapping of uses and use descriptors for the ZnO

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
IU0: SYNTHESIS / FUNCTIONALIZATION														
X								CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3 SU 8 SU 9	-	-	ERC 1
								CS 2	Synthesis	PROC 1				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling	PROC 1 PROC 2 PROC 3				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
IU1. FORMULATION														
	X							CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 10	-	-	ERC 2 ERC 3 ERC 4 ERC 5
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 10 PROC 13 PROC 26				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9 PROC 26				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
IU2. USE IN COSMETICS														
			X					CS 1	Application/ use	PROC 9 PROC 10 PROC 11 PROC 13	SU 22	PC 39	-	ERC 8b
				X				CS 1	Application/ use	-	SU 21	PC 39	-	ERC 8a ERC 8d
IU3. USE IN COATINGS AND PAINTS														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 5 SU 6a SU 6b SU 10 SU 11 SU 12 SU 13 SU 14 SU 15 SU 17 SU 19	PC 9a PC 18	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 9a PC 18	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
								CS 3	Application/use (brushing, spraying)	PROC 2 PROC 8a PROC 8b PROC 10 PROC 11 PROC 13				
				X				CS 1	Application/ use	-	SU 21	PC 9a PC 18	-	ERC 8a ERC 8d
					X			CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19	-	-	AC1 AC2 AC 3 AC4 AC5 AC6 AC8 AC10 AC13	ERC 2 ERC 3 ERC 4
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14				
								CS 3	Manual cutting, cold rolling or assembly/disassembly of material/article	PROC 21				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				
								CS 5	Sand and die casting, tapping and casting melted solids, drossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				
								CS 7	Other hot work operations with metals	PROC 25				
						X		CS 1	Application and use	PROC 21 PROC 23	-	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b
							X	CS 1	Use	-	SU 21	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b

5.2.3. Mapping of uses of Silicon Dioxide

There are various forms of synthetic amorphous silica placed on the market, including precipitated silica, silica gels, colloidal silica or silica sols and fumed or pyrogenic silica. In the food industry, silicon dioxide (synthetic amorphous silica) is authorised with specifications as food contact materials. Exposure to humans can be significant when the amorphous silica is ingested from food, or in cosmetics and pharmaceutical applications. An important source of environmental exposure is wear of tyres.

Table 7: Mapping of uses and use descriptors for the SiO_2

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
IU0: SYNTHESIS / FUNCTIONALIZATION														
X								CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3 SU 8 SU 9	-	-	ERC 1
								CS 2	Synthesis	PROC 1				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling	PROC 1 PROC 2 PROC 3				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
IU1: FORMULATION														
	X							CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 10	-	-	ERC 2 ERC 3 ERC 4 ERC 5
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 10 PROC 13 PROC 26				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9 PROC 26				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
IU2: USE IN COSMETICS														
			X					CS 1	Application/ use	PROC 9 PROC 10 PROC 11 PROC 13	SU 22	PC 39	-	ERC 8b
				X				CS 1	Application/ use	-	SU 21	PC 39	-	ERC 8a ERC 8d
IU3: USE IN COMPOSITES AND POLYMER ADDITIVES														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 3	PC 31 PC 32	-	ERC 2 ERC 3 ERC 4

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 10 PROC 13		PC 34		
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 31 PC 32 PC 34	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
								CS 3	Application/use (brushing, spraying)	PROC 2 PROC 8a PROC 8b PROC 10 PROC 11 PROC 13				
					X			CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19	-	-	AC1 AC2 AC 3 AC4 AC5 AC6 AC8 AC10 AC13	ERC 2 ERC 3 ERC 4
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14				
								CS 3	Manual cutting, cold rolling or assembly/ disassembly of material/ article	PROC 21				
								CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				
								CS 5	Sand and die casting, tapping and casting melted solids, dossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				
								CS 7	Other hot work operations with metals	PROC 25				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO									IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE										
		I	P	C	I	P	C								
						X		CS 1	Application and use		PROC 21 PROC 23	-	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b
							X	CS 1	Use		-	SU 21	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b

5.2.4. Mapping of uses of Titanium Dioxide

Around half of the global production of TiO_2 in its nanoform is intended for the personal care industry of which almost 10% are used in sunscreens. The UV filtering properties are also used to increase scratch-resistance in coatings for plastics and metals, paintings, varnishes for wood preservation or in textile fibres, dental impressions and in the production of electronic components, 'Self-cleaning' products and air purification systems take advantage of the photocatalytic and antimicrobial properties of nano-TiO_2 as well, and in dye-sensitized solar cells to produce electricity, although the efficiency is still lower than that of the traditional silicon solar cells.

Table 8: Mapping of uses and use descriptors for the TiO_2

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION	PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE								
		I	P	C	I	P	C						
IU0: SYNTHESIS / FUNCTIONALIZATION													

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
X								CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3 SU 8 SU 9	-	-	ERC 1
								CS 2	Synthesis	PROC 1				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling	PROC 1 PROC 2 PROC 3				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
IU1: FORMULATION														
	X							CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 10	-	-	ERC 2 ERC 3 ERC 4 ERC 5
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 10 PROC 13 PROC 26				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9 PROC 26				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
IU2: USE IN COSMETICS														
			X					CS 1	Application/ use	PROC 9 PROC 10 PROC 11 PROC 13	SU 22	PC 39	-	ERC 8b
				X				CS 1	Application/ use	-	SU 21	PC 39	-	ERC 8a ERC 8d
IU3: USE IN COATINGS AND PAINTS														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 5 SU 6a SU 6b	PC 9a PC 18	-	ERC 2 ERC 3 ERC 4

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 10 PROC 13	SU 10 SU 11 SU 12 SU 13 SU 14 SU 15 SU 17 SU 19			
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
								CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 9a PC 18	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
			X					CS 3	Application/use (brushing, spraying)	PROC 2 PROC 8a PROC 8b PROC 10 PROC 11 PROC 13				
				X				CS 1	Application/ use	-	SU 21	PC 9a PC 18	-	ERC 8a ERC 8d
								CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19	-	-	AC1 AC2 AC 3 AC4 AC5 AC6 AC8 AC10 AC13	ERC 2 ERC 3 ERC 4
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14				
								CS 3	Manual cutting, cold rolling or assembly/ disassembly of material/ article	PROC 21				
					X			CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				
								CS 5	Sand and die casting, tapping and casting melted solids, dossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 7	Other hot work operations with metals	PROC 25				
						X		CS 1	Application and use	PROC 21 PROC 23	-	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b
							X	CS 1	Use	-	SU 21	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b
IU4: USE IN CLEANING AGENTS														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3	PC 35	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 9 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 35	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
								CS 3	Application/use (brushing, spraying)	PROC 2 PROC 8a PROC 8b PROC 10 PROC 11 PROC 13				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
				X				CS 1	Application/ use	-	SU 21	PC 35	-	ERC 8a ERC 8d
IU5: USE AS REINFORCING MATERIAL IN PLASTIC MATRICES														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 3	PC 31 PC 32 PC 34	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Application and use	PROC 21 PROC 23	-	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b
				X				CS 1	Use	-	SU 21	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b
IU6: USE AS REINFORCING MATERIAL IN CEMENT														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 3 SU 19	PC 1 PC 9a PC 9b	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 13				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 1 PC 9a PC 9b	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
								CS 3	Application/use	PROC 2 PROC 8a PROC 8b PROC 10 PROC 13				
				X				CS 1	Application/ use	-	SU 21	PC 1 PC 9a PC 9b	-	ERC 8a ERC 8d
					X			CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19	-	-	AC4	ERC 2 ERC 3 ERC 4
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14				
								CS 3	Manual cutting, cold rolling or assembly/disassembly of material/article	PROC 21				
								CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				
								CS 5	Sand and die casting, tapping and casting melted solids, dossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				
								CS 7	Other hot work operations with metals	PROC 25				
						X		CS 1	Application and use	PROC 21 PROC 23	-	-	AC4	ERC 10a ERC 10b ERC 11a ERC 11b

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
							X	CS 1	Use	-	SU 21	-	AC4	ERC 10a ERC 10b ERC 11a ERC 11b

5.2.5. Mapping of uses of Cerium Dioxide

Nanostructured CeO_2 is principally used in the electronics sector, as films in optical and electronic devices applications, as polishing material for glass surfaces and silicon wafers or in the process of finishing photomasks and disk drives. To a lesser extent, is used as fuel catalyst where it decreases the toxic diesel emissions and increases fuel efficiency, and a small part of the global volume is used as anticorrosion material in paints, steel and other metal plates.

Table 9: Mapping of uses and use descriptors for the Ce_2O_3

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
IU0: SYNTHESIS / FUNCTIONALIZATION														
X								CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3 SU 8 SU 9	-	-	ERC 1
								CS 2	Synthesis	PROC 1				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling	PROC 1 PROC 2 PROC 3				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
IU1. FORMULATION														
	X							CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 10	-	-	ERC 2 ERC 3 ERC 4 ERC 5

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 10 PROC 13 PROC 26				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9 PROC 26				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
IU3. USE IN ELECTRONICS COMPONENTS, BATTERIES AND FUEL CELLS														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3	PC 7 PC 14 PC 0	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 9 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 7 PC 14 PC 0	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
								CS 3	Application/use	PROC 2 PROC 8a PROC 8b PROC 13				
				X				CS 1	Application/ use	-	SU 21 -	PC 7 PC 14 PC 0	-	ERC 8a ERC 8d

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
					X			CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19		-	AC1 AC2 AC 3	ERC 2 ERC 3 ERC 4
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14				
								CS 3	Manual cutting, cold rolling or assembly/disassembly of material/article	PROC 21				
								CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				
								CS 5	Sand and die casting, tapping and casting melted solids, drossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				
								CS 7	Other hot work operations with metals	PROC 25				
						X		CS 1	Application and use	PROC 21 PROC 23	-	-	AC1 AC2 AC 3	ERC 10a ERC 10b ERC 11a ERC 11b
							X	CS 1	Use	-	SU 21	-	AC1 AC2 AC 3	ERC 10a ERC 10b ERC 11a ERC 11b
IU4. USE IN FUEL CATALYST														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 3	PC 13	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 13	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
								CS 3	Application/use (brushing, spraying)	PROC 2 PROC 8a PROC 8b				
				X				CS 1	Application/use	-	SU 21	PC 13	-	ERC 8a ERC 8d
U5. USE IN COATINGS AND PAINTS														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 5 SU 6a SU 6b SU 10 SU 11 SU 12 SU 13 SU 14 SU 15 SU 17 SU 19	PC 9a PC 18	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 9a PC 18	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
								CS 3	Application/use (brushing, spraying)	PROC 2 PROC 8a PROC 8b PROC 10 PROC 11 PROC 13				
				X				CS 1	Application/ use	-	SU 21	PC 9a PC 18	-	ERC 8a ERC 8d
					X			CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19	-	-	AC1 AC2 AC 3 AC4 AC5 AC6 AC8 AC10 AC13	ERC 2 ERC 3 ERC 4
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14				
								CS 3	Manual cutting, cold rolling or assembly/disassembly of material/article	PROC 21				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				
								CS 5	Sand and die casting, tapping and casting melted solids, drossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				
								CS 7	Other hot work operations with metals	PROC 25				
						X		CS 1	Application and use	PROC 21 PROC 23	-	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b
							X	CS 1	Use	-	SU 21	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b

5.2.6. Mapping of uses of Calcium Carbonate

Most of the calcium carbonate in the market cannot be considered nanomaterial (it has sizes above 100 nm), although there are some nanoforms that are widely used as fillers in paper, plastics, paints and coatings, adhesives and sealants. However, the information available is rather scarce. Due to lack of information for the time being, the use of $CaCO_3$ in plastics and paints and coatings have been included in the study.

Table 10: Mapping of uses and use descriptors for the $CaCO_3$

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
IU0: SYNTHESIS / FUNCTIONALIZATION														
X								CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3 SU 8 SU 9	-	-	ERC 1
								CS 2	Synthesis	PROC 1				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling	PROC 1 PROC 2 PROC 3				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
IU1. FORMULATION														
	X							CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 10	-	-	ERC 2 ERC 3 ERC 4 ERC 5
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 10 PROC 13 PROC 26				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9 PROC 26				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
IU3. USE IN COMPOSITES AND POLYMER ADDITIVES														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 3	PC 31 PC 32 PC 34	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 31 PC 32 PC 34	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
								CS 3	Application/use	PROC 2 PROC 8a PROC 8b PROC 10 PROC 11 PROC 13				
					X			CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19	-	-	AC1 AC2 AC 3 AC4 AC5 AC6 AC8 AC10 AC13	ERC 2 ERC 3 ERC 4
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14				
								CS 3	Manual cutting, cold rolling or assembly/disassembly of material/article	PROC 21				
								CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				
								CS 5	Sand and die casting, tapping and casting melted solids, drossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				
								CS 7	Other hot work operations with metals	PROC 25				
						X		CS 1	Application and use	PROC 21 PROC 23	-	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
							X	CS 1	Use	-	SU 21	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b

5.2.7. Mapping of uses of Carbon Nanotubes

Carbon nanotubes consist of one or more layers of carbon concentric sheets that are arranged exactly like the carbon atoms are arranged in ordinary graphite. Depending on the structure of the tube and the number of layers (single- double- or multi-walled), they may exhibit high thermal and electronic conductivity and a high strength-to-weight ratio.

Thinner CNT are mainly used as means for imparting electrical conductivity to plastic materials as in the case of disk drive components or automotive plastic fuel lines and fenders. They can be used as well as polymer additives, in paints and coatings in fuel cells, electrodes, electrolytes and membranes in miniature lithium batteries.

Larger CNTs are mainly used in lithium ion batteries, fuel cells, fabrics for filtration or in plastic compounds for fuel lines. It should be noted moreover that CNT are being studied intensively aiming to find new applications.

Table 11: Mapping of uses and use descriptors for the CNTs

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
IU0: SYNTHESIS / FUNCTIONALIZATION														
X								CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3 SU 8 SU 9	-	-	ERC 1
								CS 2	Synthesis	PROC 1				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 4	Sampling	PROC 1 PROC 2 PROC 3				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
IU1. FORMULATION														
	X							CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 10	-	-	ERC 2 ERC 3 ERC 4 ERC 5
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9 PROC 26				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
IU2. USE IN COMPOSITES AND POLYMER ADDITIVES														
		x						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 3	PC 31 PC 32 PC 34	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			x					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 31 PC 32 PC 34	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 3	Application/use	PROC 2 PROC 8a PROC 8b PROC 10 PROC 11 PROC 13				
					X			CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19	-	-	AC1 AC2 AC 3 AC4 AC5 AC6 AC8 AC10 AC13	ERC 2 ERC 3 ERC 4
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14				
								CS 3	Manual cutting, cold rolling or assembly/disassembly of material/article	PROC 21				
								CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				
								CS 5	Sand and die casting, tapping and casting melted solids, drossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				
								CS 7	Other hot work operations with metals	PROC 25				
						X		CS 1	Application and use	PROC 21 PROC 23	-	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
							X	CS 1	Use	-	SU 21	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b
IU3.USE IN ELECTRONIC COMPONENTS, BATTERIES AND FUEL CELLS														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3	PC 7 PC 14 PC 0	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 9 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 7 PC 14 PC 0	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
								CS 3	Application/use	PROC 2 PROC 8a PROC 8b PROC 13				
				X				CS 1	Application/ use	-	SU 21 -	PC 7 PC 14 PC 0	-	ERC 8a ERC 8d
					X			CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19		-	AC1 AC2 AC 3	ERC 2 ERC 3 ERC 4
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14				
								CS 3	Manual cutting, cold rolling or assembly/disassembly of material/article	PROC 21				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				
								CS 5	Sand and die casting, tapping and casting melted solids, drossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				
								CS 7	Other hot work operations with metals	PROC 25				
						X		CS 1	Application and use	PROC 21 PROC 23	-	-	AC1 AC2 AC 3	ERC 10a ERC 10b ERC 11a ERC 11b
							X	CS 1	Use	-	SU 21	-	AC1 AC2 AC 3	ERC 10a ERC 10b ERC 11a ERC 11b
IU4. USE IN RESEARCH AND DEVELOPMENT														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3 SU 10 SU 24	PC 19 PC 21	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 9 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 19 PC 21	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 3	Application/use (brushing, spraying)	PROC 2 PROC 8a PROC 8b PROC 10 PROC 11 PROC 13				
IU5. USE AS REINFORCING MATERIAL IN CEMENT														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 3 SU 19	PC 1 PC 9a PC 9b	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 1 PC 9a PC 9b	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
								CS 3	Application/use	PROC 2 PROC 8a PROC 8b PROC 10 PROC 13				
				X				CS 1	Application/ use	-	SU 21	PC 1 PC 9a PC 9b	-	ERC 8a ERC 8d
					X			CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19	-	-	AC4	ERC 2 ERC 3 ERC 4
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14				
								CS 3	Manual cutting, cold rolling or assembly/disassembly of material/article	PROC 21				
								CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 5	Sand and die casting, tapping and casting melted solids, drossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				
								CS 7	Other hot work operations with metals	PROC 25				
						X		CS 1	Application and use	PROC 21 PROC 23	-	-	AC4	ERC 10a ERC 10b ERC 11a ERC 11b
							X	CS 1	Use	-	SU 21	-	AC4	ERC 10a ERC 10b ERC 11a ERC 11b

5.2.8. Mapping of uses of Graphene

Graphene has normally only one dimension in the nanoscale due to its flake shape. It consists of a semi-metal or zero-gap semiconductor, thus it has a very high electron mobility at room temperature, a high opacity and a number of other properties which makes them a promising material for a number of applications, even though market development is still at an early stage.

Main applications are related with electronics, such as sensors, graphene transistors, integrated circuits, electrochromic devices, transparent conducting electrodes, solar and fuel cells, antimicrobial materials, specific materials for aircraft (e.g. lightning strike protection, prevention of ice adhesion, radiation hardness) and the automotive industry (e.g. prevention of static build-up on fuel lines).

Table 12: Mapping of uses and use descriptors for the Graphene

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
IU0: SYNTHESIS / FUNCTIONALIZATION														
X								CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3 SU 8 SU 9	-	-	ERC 1
								CS 2	Synthesis	PROC 1				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling	PROC 1 PROC 2 PROC 3				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
IU1: USE IN ELECTRONICS COMPONENTS, BATTERIES AND FUEL CELLS														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3	PC 7 PC 14 PC 0	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 9 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 7 PC 14 PC 0	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
								CS 3	Application/use	PROC 2 PROC 8a PROC 8b PROC 13				
				X				CS 1	Application/ use	-	SU 21	PC 7 PC 14 PC 0	-	ERC 8a ERC 8d
					X			CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19	-	-	AC1 AC2 AC 3	ERC 2 ERC 3 ERC 4

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14				
								CS 3	Manual cutting, cold rolling or assembly/ disassembly of material/ article	PROC 21				
								CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				
								CS 5	Sand and die casting, tapping and casting melted solids, dossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				
								CS 7	Other hot work operations with metals	PROC 25				
						X		CS 1	Application and use	PROC 21 PROC 23	-	-	AC 1 AC 2 AC 3	ERC 10a ERC 10b ERC 11a ERC 11b
							X	CS 1	Use	-	SU 21	-	AC 1 AC 2 AC 3	ERC 10a ERC 10b ERC 11a ERC 11b

5.2.9. Mapping of uses of Fullerenes

Fullerenes are in fact molecules that consist of an even number of 60 or more carbon atoms. They can be used as additives in composites for sports equipment manufacturing like tennis rackets, gold balls or in cosmetics, fuel cells, lithium battery anodes, solar cells components etc. However even though the application range of fullerenes appears to be wide, most of it is used in research and development.

Table 13: Mapping of uses and use descriptors for the Fullerenes

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
IU0: SYNTHESIS / FUNCTIONALIZATION														
X								CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3 SU 8 SU 9	-	-	ERC 1
								CS 2	Synthesis	PROC 1				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling	PROC 1 PROC 2 PROC 3				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
IU1. FORMULATION														
	X							CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 10	-	-	ERC 2 ERC 3 ERC 4 ERC 5
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9 PROC 26				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
IU2. USE IN RESEARCH AND DEVELOPMENT														
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19 PROC 26	SU 3 SU 10 SU 24	PC 19 PC 21	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 7 PROC 9 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
								CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 19 PC 21	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
			X					CS 3	Application/use (brushing, spraying)	PROC 2 PROC 8a PROC 8b PROC 10 PROC 11 PROC 13				

5.2.10. Mapping of uses of Nanocelluloses

The main use of nanocellulosic products is related with packaging, hygiene, textiles, plastic Film applications and the paper industry, although cement has a potential nanocellulose market size. The study found that the majority of the near-term market potential for nanocellulose appears to be in its fibrillary versus crystalline form.

Table 14: Mapping of uses and use descriptors for Nanocellulose.

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
IU0: SYNTHESIS / FUNCTIONALIZATION														
X								CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 3 SU 8 SU 9	-	-	ERC 1
								CS 2	Synthesis	PROC 1				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling	PROC 1 PROC 2 PROC 3				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
IU1. USE IN COMPOSITES AND POLYMER ADDITIVES														

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO								IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE									
		I	P	C	I	P	C							
		X						CS 1	Handling/ Weighing	PROC 9 PROC 15 PROC 19	SU 3	PC 31 PC 32 PC 34	-	ERC 2 ERC 3 ERC 4
								CS 2	Mixing	PROC 2 PROC 3 PROC 4 PROC 5 PROC 10 PROC 13				
								CS 3	Loading/ Packing	PROC 8a PROC 8b PROC 9				
								CS 4	Sampling, Quality control	PROC 2 PROC 15				
								CS 5	Cleaning and maintenance	PROC 8a PROC 19				
								CS 6	Storage and distribution	PROC 1				
			X					CS 1	Handling/ Weighing	PROC 15 PROC 19	SU 22	PC 31 PC 32 PC 34	-	ERC 8a ERC 8b
								CS 2	Mixing	PROC 5				
								CS 3	Application/use (brushing, spraying)	PROC 2 PROC 8a PROC 8b PROC 10 PROC 11 PROC 13				
					X			CS 1	Handling, weighing and mixing	PROC 9 PROC 15 PROC 19	-	-	AC1 AC2 AC 3 AC4 AC5 AC6 AC8 AC10 AC13	ERC 2 ERC 3 ERC 4
								CS 2	Production of articles by tabletting, compression, extrusion, pelletisation	PROC 14				
								CS 3	Manual cutting, cold rolling or assembly/disassembly of material/article	PROC 21				
								CS 4	Activities at smelters, furnaces, refineries, coke ovens	PROC 22				
								CS 5	Sand and die casting, tapping and casting melted solids, drossing of melted solids, hot dip galvanising, raking of melted solids in paving	PROC 23				
								CS 6	High (mechanical) energy work-up of substances bound in materials and/or articles	PROC 24				

LIFE CYCLE STAGE COVERED BY THE EXPOSURE SCENARIO							IU DESCRIPTION		PROCESS CATEGORIES (PROC)	SECTOR OF USE (SU)	PRODUCT CATEGORY (PC)	ARTICLE CATEGORY (AC)	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
MANUFACTURE	FORMULATION	USE			SERVICE LIFE								
		I	P	C	I	P	C								
								CS 7	Other hot work operations with metals	PROC 25				
						X		CS 1	Application and use	PROC 21 PROC 23	-	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b
							X	CS 1	Use	-	SU 21	-	AC2 AC 3 AC4 AC5 AC6 AC 7 AC8 AC10 AC13	ERC 10a ERC 10b ERC 11a ERC 11b

5.3. Main sources and levels of exposure

In general, the most important source of human exposure appears to be workplace exposure via inhalation or dermal contact. Populations living in areas surrounding hazardous waste sites may be exposed to ENMs through inhalation of contaminated air and ingestion or dermal contact with contaminated water; the latter being particularly important for populations living near certain types of disposal sites (e.g., underground sites), being as well an important cause of environmental exposure as well.

The relative importance of these pathways in terms of human exposure potential is difficult to establish given the limited monitoring data available for ENMs. Most people, however, are probably exposed to very small amounts of ENMs through: (1) inhalation of contaminated ambient air and fumes; (2) dermal contact with products containing the compound (e.g., glues, textiles or paints); and (3) ingestion of foods with residual traces (i.e., that may have migrated from plastic food wraps) or intentional additives such as food items containing compounds as a starch modifier.

A summary of relevant sources of nanoparticles in the workplace extracted from peer reviewed publications is listed in Table 15. Data on typical concentration ranges are also included in the table. It must be remarked that due to the scarcity of measured data, most of the information is focused in occupational exposure via inhalation, being consumer and environmental exposures still largely unknown.

The main focus of the review has been to attempt to identify tasks where exposure to ENMs has been measured, with the aim of in the future assign a suitable 'indicator value' of exposure e.g. read across exposure from an analogous process in the literature to the tasks identified during the scoping visits with the NanoMonitor device. This should give some idea of the exposures that humans and environment might experience. Some interpolation or projection of how activities and operations performed in laboratory and pilot plants might be carried out on an industrial scale has to be considered.

Exposure can change from significant to negligible when the effect of exposure control is considered e.g. containment, ventilation, automation, manual intervention, respiratory protection. However, in addition to these exposure parameters, issues surrounding the monitoring instruments employed and the treatment and display of exposure measurements have to be considered including:

- the compatibility between measurements obtained from different instruments when used to derive particle concentration over a new size range, either 'additively' (so as to cover a size range greater than either of instruments alone) or by 'difference' (to derive the particle concentration for a size range in between that of the two instruments);
- measuring and sampling in near and far field locations
- 'speciation' of the real time quantitative measurements by application of qualitative analyses results;
- selection of relevant and representative ambient and workplace background situations;
- application of ambient and workplace background level measurements to adjust process emission measurements;
- identifying and evaluating nano-contributions to emission from process-related and other anthropogenic sources of incidental nanoparticles, from natural sources, from disturbances created by forced or natural air movement and from workers' movements when interacting with the processes, and
- recognising when a nanomaterial is a 'true' ENM and when it originates from the 'normal' particle size distribution of a typical 'non-nano' source.

Exposure and emission related information has been extracted from the published literature and summarised in Table 15, along with a classification on "*Very Likely*", "*Likely*", "*Possible*" and "*Unlikely*", rated from higher to lower potential of exposure to the ENM studied.

Table 15. Examples of source domains along with exposure potential and measured ranges.

Emission Source	ENM	Measured level range (part/cm^3)	Exposure potential	Ref.
SD1				
Liquid-phase reaction	Ag	4.0x10^4 to 11.0x10^6	**Likely**	21
Flame spraying	CeO_2 & others	4.7x10^3 to 1.0x10^6	**Likely**	22, 23, 24

[21] Park et al, "Characterization of exposure to silver nanoparticles in a manufacturing facility," *J Nanopart Res,* vol. 11, p. 1705–1712, 2009.
[22] Leppänen M. et al, "Exposure to CeO2 nanoparticles during flame spray process," Nanotoxicology, vol. 6, no. 6, pp. 643-51, 2012.
[23] Walser et al, "Exposure to engineered nanoparticles: Model and measurements for accident situations in laboratories," Science of the Total Environment, vol. 420, pp. 119 - 126, 2012.
[24] Koponen et al., "Study on nanoparticle aerosol emission and evolution using laboratory scale liquid flame spray nanoparticle generation system," FP7 Nanodevice, 2013.

Emission Source	ENM	Measured level range (part/cm^3)	Exposure potential	Ref.
CVD	CNT	Non-significant	**Possible**	25
Top-down (milling)			**Possible**	
Synthesis of nanocellulose dispersion, coating and homogenisation of product for food industry (packaging)	Nanocellulose	Non-significant	**Very Unlikely**	41
Industrial production of water based paints in agitator reactor	TiO_2	$6.12x10^4$	**Unlikely**	26
Nanoparticle Spray drying and combustion & chemical reactions	TiO_2, Al_2O_3, Fe_2O_3 & 3 other nano-metal oxides	$3.8X10^4$	**Likely**	27
Pilot scale synthesis by a plasma-based technique	Ag	$5.3x10^2$ to $6.67x10^3$	**Unlikely**	28
Laboratory synthesis By chemical reduction & precipitation	Ag	$3.9x10^2$ to $3.5x10^3$	**Unlikely**	28
SD2				
Weighing of powders		$2.0X10^4$ to $7.0x10^4$	**Likely**	29
Harvesting		$2.0X10^4$ to $5.0x10^4$	**Likely**	29
Manual packaging (Bagging)	TiO_2, Al_2O_3	$20.0x10^4$	**Likely**	30
Bag emptying of powders	TiO_2	Significant increase	**Likely**	31, 32
Melt Blending	Al	$> 1.0x10^5$	**Likely**	33
Industrial bagging	$CaCO_3$	$4.9X10^4$	**Unlikely**	34

[25] Ogura et al, "Release potential of single-wall carbon nanotubes produced by super-growth method during manufacturing and handling," J Nanopart Res, vol. 13, pp. 1265-1280, 2011.

[26] Broekhuizen, P., Broekhuizen, F., Cornelissen, R., & Reijnders, L. (2012). Workplace exposure to nano-particles and the application of provisional nano-reference values in times of uncertain risks. Journal of Nanoparticle Research, 14(4), 770.

[27] Curwin, B., & Bertke, S. (2011). Exposure characterization of metal oxide nano-particles in the workplace. Journal of Occupational and Environmental Hygiene, 8(10), 580–7.

[28] Lee, J-H., Kwon, M., Ji, J-H., Kang, C-S., Ahn, K-H., Han, J-H., & Yu, I-J. (2011). Exposure assessment of workplaces manufacturing nano-sized TiO2 and silver. Inhalation Toxicology, 23(4), 226–36.

[29] Sally Spankie et al, "Deliverable 4.2. NanoMICEX project," 2015.

[30] Heinz Kaminski, et al, "Measurements of Nanoscale TiO2 and Al2O3 in Industrial Workplace Environments – Methodology and Results," Aerosol and Air Quality Research, vol. 15, pp. 129-141, 2015.

[31] Brouwer et al, "From workplace air measurement results toward estimates of exposure? Development of a strategy to assess exposure to manufactured nano-objects," Journal of Nanoparticle Research, vol. 11, no. 8, pp. 1867-1881, 2009.

[32] Koivisto et al, "Industrial worker exposure to airborne particles during the packing of pigment and nanoscale titanium dioxide," Inhalation Toxicology, vol. 24, no. 12, p. 839–849, 2012.

[33] Tsai, S. el al, "Airborne nanoparticle release associated with the compounding of nanocomposites using nanoalumina as fillers," Aerosol Air Qual. Res., vol. 8, no. 2, pp. 160-177, 2008.

[34] Tsai, C-J., Huang, C-Y., Chen, S-C., Ho, C-E., Huang, C-H., Chen, C-W., Chang, C-P., Tsai S-J., & Ellenbecker, M. J. (2011). Exposure assessment of nano-sized and respirable particles at different workplaces. Journal of Nanoparticle Research, 13(9), 4161–4172.

Emission Source	ENM	Measured level range (part/cm^3)	Exposure potential	Ref.
Weighing, mixing, pouring & recovery (syntheses and end use).	TiO_2, Al_2O_3, Fe_2O_3 & 3 other nano-metal oxides	$1.3X10^4$	**Possible**	27
Handling & Pouring <100g of ENMs	Al_2O_3, Ag	$1.5x10^3$ to $1.4x10^4$	**Possible**	35
SD3				
Spraying of liquid	Ti	$2.0x10^8$	**Very Likely**	36
Spraying (gas)		$1.6x10^5$ to $2.0x10^{10}$	**Very Likely**	37, 38
Injection Molding		$> 8.0x10^5$	**Very Likely**	31
Brushing and rolling		$> 6.0x10^5$	**Very Likely**	39
Sonication of nanodispersions	Si, SiO_2	$> 8.0x10^6$	**Very Likely**	40
Spraying antifouling paint	ZnO	4.1 to $5.5x10^4$	**Possible**	41
Spraying on concrete	TiO_2	1.6 to 2.2 $x10^3$	**Possible**	41
Padding of antibacterial textiles	Ag	$3.9x10^4$ to $1.55x10^5$	**Unlikely**	41
Environmental soil remediation	FeO	Non-significant	**Unlikely**	41
Nanocoating for household products	TiO_2	Non-significant	**Possible**	41
Spraying antislip coating on tiles (consumer goods)	Al_2O_3, SiO_2	6.5 to $8.1x10^4$	**Unlikely for inhalation** **Likely for dermal**	41
	TiO_2	3.5 to $6.1x10^4$	**Likely inhalation & dermal**	41
SD4				
Abrasion of nanoproducts	CNT	$8.0x10^3$ to $2.0x10^4$	**Possible**	42
Drilling		$4.0x10^4$	**Possible**	43

[35] Tsai, S-J, Ada E., Isaacs J., & Ellenbecker M. J. (2009). Airborne nanoparticle exposures associated with the manual handling of nano-alumina and nano-silver in fume hoods. Journal of Nanoparticle Research. January 2009, 11(1), 147-161

[36] Dylla at al., "Characterization of nanoparticles released during construction of photocatalytic pavements using engineered nanoparticles.," J Nanopart Res, vol. 14, no. 4, 2012.

[37] Norgaard et al, "Release of VOCs and particles during use of nanofilm spray products," Environ Sci Technol, vol. 43, p. 7824–7830., 2009.

[38] Chen et al, "Nanoparticles-containing spray can aerosol: Characterization, exposure assessment, and generator design.," InhalToxicol, vol. 22, p. 1072–1082., 2010.

[39] Kuhlbusch et al, "Nanoparticle exposure at nanotechnology workplaces: A review," Particle and Fibre Toxicology 2011, vol. 8, no. 22, 2011.

[40] Boowook et al, "Assessment of nanoparticle exposure in nanosilica handling process," Industrial Health, vol. 52, pp. 152-162, 2014.

[41] Guidenano Project (FP7/2007-2013) under grant agreement №604387 http://www.guidenano.eu/

[42] Schlagenhauf, L. et al, "Release of carbon nanotubes from an epoxy-based nanocomposite during an abrasion process," Environ Sci Technol 46, vol. 46, no. 13, p. 7366–7372., 2012.

[43] Van Broekhuizen P. et al, "Exposure Limit Values for Nanomaterials. Capacity and Willingness of Users to Apply a Precautionary Approach," *Journal of Occupational and Environmental Hygiene,* vol. 10, p. 46–53, 2012.

Emission Source	ENM	Measured level range (part/cm^3)	Exposure potential	Ref.
Grinding	CNT	3.0x10^3 to 1.0x10^6	**Possible**	44, 45
Extrusion of polymers & CNTs	MWCNTs (powder)	2.3x10^4	**Likely**	41
	MWCNTs (masterbatch)	3.0x10^4	**Unlikely**	41

Researchers frequently use more than one monitoring method and multiple instruments simultaneously in order to cover wider size ranges. There is also variability in how the authors treat data obtained, e.g. apply background measurements to 'correct' process measurements, use qualitative analyses and the level of contextual data gathered and applied. This may well arise from a lack of any single or composite standard method for monitoring nanoparticles being currently available.

The criteria used to decide whether exposure was likely or not for the scenario involved in the case studies has been developed by Bekker et al (2014)[46] and forms the basis for currently developed European Committee for Standardization (CEN) criteria concerning workplace assessment of Nano-Objects and their Agglomerates and Aggregates (NOAA). The international acceptance of the specific method and its ability to fit a broad range of scenarios with limited influence by existing differences in applied sampling and analytical methodologies were the main reasons for the adaptation of the specific method instead of other methods available[47].

The likelihood of exposure assessment was based on the results of both the personal and stationary measurements performed. In case of contradictory results between different instruments, weight was given to those demonstrating that the likelihood of exposure was not unlikely. For example, if SEM/EDX analysis verified the presence of the ENM in process samples, secondary sources were absent, but the personal monitoring which was performed with 2 different instruments returned contradictory results – i.e. one instrument showed levels to be significantly higher than background while the other did not – then exposure was assumed to be likely. Whenever possible, differences in exposure concentrations between processes and the background were evaluated on the basis of the results of formal statistical tests. When these were not available, then an increase by 10% in the average levels of exposure during the process relatively to the background (i.e. process/background concentration ratio = 1.1) was considered as sufficient to indicate that particle concentrations increased as a results of the involved process. This low cut-off level was applied with the aim to minimise the potential of an increased number of false negative assessments. When off-line analyses on background samples were not

[44] K.L. Van Landuyt et al, "Nanoparticle release from dental composites," Acta Biomaterialia, vol. 10, p. 365–374, 2014.

[45] Fleury et al, "Identification of the main exposure scenarios in the production of CNT-polymer nanocomposites by melt-moulding process," Journal of Cleaner Production, pp. 1-15, 2011.

[46] Bekker C, Brouwer DH, van Duuren-Stuurman B, Tuinman II, Tromp P, Fransman W. (2014) Airborne manufactured nano-objects released from commercially available spray products: temporal and spatial influences. JESEE; 24: 74-81.

[47] Brouwer DH, van Duuren-Stuurman B, Berges M, Jankowska E, Bard Delphine, Mark D. (2009) From workplace air measurement results toward estimates of exposure? Development of strategy to assess exposure to manufactured nano-objects. Journal of Nanoparticle Research, 11: 1867–1881.

available, then the likelihood of exposure was assigned assuming that the ENM was absent from background.

The data compiled from the peer reviewed publications were gathered to group relevant activities according with the likelihood of exposure. In general, processes of wide dispersive uses such as spraying can lead to a significant increase in the amount of ENMs released. It is detected as well a significant release rate in processes involving the application of frictional forces and pressure, both resulting in the release of ENMs in quantities up to $2.0x10^{10}$ particles/cm^3. Other conventional processes such as harvesting and cleaning operations can generate a significant exposure to ENMs, being highly recommend to implement administrative procedures and controls aimed at reducing the release of ENMs to background levels.

Mayor concerns are expected from wide dispersive applications such as the spraying of liquid dispersions containing ENMs and grinding processes. In these process, where the likelihood of exposure has been considered **very likely**, is highly recommended the implementation of controls or the improvement of the enclosure to avoid the transport of the particles released from the source to the receptors.

In fact, there exists a potential release of nanoparticles during all stages of the life cycle, from production, downstream use, accidental spills, and consumer use, to end-of-life treatments. However, there is little evidence supporting the release of the specific types of ENMs being manufactured and/or handled at industrial sites, which highlights the importance of the background aerosols and the need of clearly identify the origin of the particles monitored and/or sampled in different environments.

It shall be noticed that there is a current lack of data on the release rate of nanoparticles from conventional sources, most of studies focused on the quantification of the ENMs in occupational settings. This limits the development of accurate predictive models commonly used for risk assessment purposes. Similarly, the mechanism affecting the transport of the ENMs released are not sufficiently understood, therefore, the nature and extent of the exposure to nanoparticles in urban, rural or environmental compartments can only be defined measuring and characterizing the size and chemical nature of the ENMs detected.

6. Conclusions

The present document aims to provide a series of exposure scenarios and quantitative exposure potentials on them for the most widespread ENMs. Exposure scenarios are useful tools for the exposure assessment as a basis for quantitative exposure estimation. ES within REACH are defined as '*sets of information describing the conditions under which the risk associated with the identified use(s) of a substance can be controlled*'. ES are made up of a number of contributing exposure scenarios, developed from the descriptions of the process, by process step, considering the material streams, the plant (apparatus, equipment and machinery used), plant operations, operational conditions, RMMs present and grouped together operations or activities where exposure is likely to be similar.

Exposure can occur through inhalation, dermal contact and ingestion. Inhalation exposure is widely considered to be the main route of exposure. Dermal and ingestion exposure can also occur but is generally considered to be of lower importance, since exposure to humans and the environment is estimated to be rather low when the material is normally fixed in a matrix. However, behaviour ENMs at the end-of-life stage is still unknown and further research must be conducted.

The outcomes of the studies reviewed to develop this deliverable show that, in practice, each situation should be treated differently in terms of exposure considerations. A thorough analysis of the possible sources of exposure and modifying factors should be completed prior to adequately conduct quantitative assessment of the levels of exposure in workplaces. This assumption does not imply the lack of a specific pattern in the release behaviour of ENMs.

Gaps in activity data, impossibility of monitoring at all potential sources simultaneously and the assumption that the initial background reading does not fluctuate lead to difficulties in assigning measurements to ENMs exposure. However, qualitative (elemental) analyses of filter samples for particle composition, together with a (time) log of when ENM-related activities occurred, were used to try and assign airborne concentrations measurements to nanoparticle release sources and activities.

The results from the measurement campaigns analysed showed that there was variable evidence of exposure to the target ENMs during the various activities evaluated, depending on variables relying on intrinsic characteristics of the ENM (dustiness, primary size, density, solubility…) and process-related properties, such as energy of the process, life cycle stage of the ENM, temperature and humidity conditions, neighbour activities or RMMs available. All these factors can increase or reduce the exposure potential for the same ENM analysed, independently of the concentration levels reached at the source or workplace.

The inventory of exposure scenarios will be further compiled and updated in an Excel sheet based on the information retrieved in task B1.1 and the data compiled within action A3., organized by sectors and types of ENMs, including detailed information on the operative conditions, risk controls and levels of exposure based on measured data in a specific stage across the life cycle of the target ENMs. The structure of the exposure scenarios will be based on the ECHA guidance on Risk Management Measures and Operative Conditions, in order to support the identification of priority sectors and exposure scenarios where the use of measured data will promote the health surveillance and the protection of the human health and the environments.

7. Annex

Regulation (EC) No 1907/2006 of the European Parliament and of the Council (REACH) requires communication in the supply chain between Manufacturers/Importers and their Downstream Users to identify product END-USES. There may also be a further obligation for you to communicate with your customers to identify their end-uses. these uses are identified in a standard format that utilises the ECHA Use Descriptor System. End-uses will provide the basis for making a Chemical Safety Assessment, which is a key step in substance registration under REACH.

If your end uses are not identified, they may not be covered by the registration and consequently would not comply with REACH. The ECHA system for describing end-use employs a 5-element coding process, which is intended to give a short-hand means for characterising the infinite number of uses of substances throughout Europe. The following table gives an overview of the elements of the scheme. More information on the use descriptor scheme can be found in the ECHA guidance:
http://echa.europa.eu/documents/10162/17224/information_requirements_r12_en.pdf.

A1. Descriptors by Process Categories

DESCRIPTOR	PROCESS CATEGORIES (PROC)
PROC 0	
PROC 1	Use in closed process, no likelihood of exposure
	Use of the substances in high integrity contained system where little potential exists for exposures, e.g. any sampling via closed loop systems
PROC 2	Use in closed, continuous process with occasional controlled exposure
	Continuous process but where the design philosophy is not specifically aimed at minimizing emissions It is not high integrity and occasional expose will arise e.g. through maintenance, sampling and equipment breakages
PROC 3	Use in closed batch process (synthesis or formulation)
	Batch manufacture of a chemical or formulation where the predominant handling is in a contained manner, e.g. through enclosed transfers, but where some opportunity for contact with chemicals occurs, e.g. through sampling
PROC 4	Use in batch and other process (synthesis) where opportunity for exposure arises
	Use in batch manufacture of a chemical where significant opportunity for exposure arises, e.g. during charging, sampling or discharge of material, and when the nature of the design is likely to result in exposure
PROC 5	Mixing or blending in batch processes for formulation of preparations* and articles (multistage and/or significant con-tact)
	Manufacture or formulation of chemical products or articles using technologies related to mixing and blending of solid or liquid materials, and where the process is in stages and provides the opportunity for significant con-tact at any stage
PROC 6	Calendering operations
	Processing of product matrix at elevated temperature a large exposed surface
PROC 7	Industrial spraying

	Air dispersive techniques Spraying for surface coating, adhesives, polishes/cleaners, air care products, sandblasting. Substances can be inhaled as aerosols. The energy of the aerosol particles may require advanced exposure controls; in case of coating, overspray may lead to waste water and waste.
PROC 8a	Transfer of substance or preparation (charging/discharging) from/to vessels/large containers at non-dedicated facilities
	Sampling, loading, filling, transfer, dumping, bagging in non- dedicated facilities. Exposure related to dust, vapour, aerosols or spillage, and cleaning of equipment to be expected.
PROC 8b	Transfer of substance or preparation (charging/discharging) from/to vessels/large containers at dedicated facilities
	Sampling, loading, filling, transfer, dumping, bagging in dedicated facilities. Exposure related to dust, vapour, aerosols or spillage, and cleaning of equipment to be expected.
PROC 9	Transfer of substance or preparation into small containers (dedicated filling line, including weighing)
	Filling lines specifically designed to both capture vapour and aerosol emissions and minimise spillage
PROC 10	Roller application or brushing
	Low energy spreading of e.g. coatings Including cleaning of surfaces. Substance can be inhaled as vapours, skin contact can occur through droplets, splashes, working with wipes and handling of treated sur-faces.
PROC 11	Non industrial spraying
	Air dispersive techniques Spraying for surface coating, adhesives, polishes/cleaners, air care products, sandblasting Substances can be inhaled as aerosols. The energy of the aerosol particles may require advanced exposure controls.
PROC 12	Use of blowing agents in manufacture of foam
	Non defined by ECHA
PROC 13	Treatment of articles by dipping and pouring
	Immersion operations Treatment of articles by dipping, pouring, immersing, soaking, washing out or washing in substances; including cold formation or resin type matrix. Includes handling of treated objects (e.g. after dying, plating,). Substance is applied to a surface by low energy techniques such as dipping the article into a bath or pouring a preparation onto a surface.
PROC 14	Production of preparations* or articles by tabletting, compression, extrusion, pelletisation
	Processing of preparations and/or substances (liquid and solid) into preparations or articles. Substances in the chemical matrix may be exposed to elevated mechanical and/or thermal energy conditions. Exposure is predominantly related to volatiles and/or generated fumes; dust may be formed as well.
PROC 15	Use as laboratory reagent
	Use of substances at small scale laboratory (< 1 l or 1 kg present at workplace). Larger laboratories and R+D installations should be treated as industrial processes
PROC 16	Using material as fuel sources, limited exposure to unburned product to be expected
	Covers the use of material as fuel sources (including additives) where limited exposure to the product in its un-burned form is expected. Does not cover exposure as a consequence of spillage or combustion.

PROC 17	Lubrication at high energy conditions and in partly open process
	Lubrication at high energy conditions (temperature, friction) between moving parts and substance; significant part of process is open to workers. The metal working fluid may form aerosols or fumes due to rapidly moving metal parts.
PROC 18	Greasing at high energy conditions
	Use as lubricant where significant energy or temperature is applied between the substance and the moving parts
PROC 19	Hand-mixing with intimate contact and only PPE available
	Addresses occupations where intimate and intentional contact with substances occurs without any specific exposure controls other than PPE
PROC 20	Heat and pressure transfer fluids in dispersive, professional use but closed systems
	Motor and engine oils, brake fluids Also in these applications, the lubricant may be exposed to high energy conditions and chemical reactions may take place during use. Exhausted fluids need to be disposed of as waste. Repair and maintenance may lead to skin contact.
PROC 21	Low energy manipulation of substances bound in materials and/or articles
	Manual cutting, cold rolling or assembly/disassembly of material/article (including metals in massive form), possibly resulting in the release of fibres, metal fumes or dust
PROC 22	Potentially closed processing operations with minerals/metals at elevated temperature Industrial setting
	Activities at smelters, furnaces, refineries, coke ovens. Exposure related to dust and fumes to be expected. Emission from direct cooling may be relevant
PROC 23	Open processing and transfer operations with minerals/metals at elevated temperature
	Sand and die casting, tapping and casting melted solids, drossing of melted solids, hot dip galvanising, raking of melted solids in paving Exposure related to dust and fumes to be expected
PROC 24	High (mechanical) energy work-up of substances bound in materials and/or articles
	Substantial thermal or kinetic energy applied to sub-stance (including metals in massive form) by hot rolling/forming, grinding, mechanical cutting, drilling or sanding. Exposure is predominantly expected to be to dust. Dust or aerosol emission as result of direct cooling may be expected.
PROC 25	Other hot work operations with metals
	Welding, soldering, gouging, brazing, flame cutting Exposure is predominantly expected to fumes and gases.
PROC 26	Handling of solid inorganic substances at ambient temperature
	Transfer and handling of ores, concentrates, raw metal oxides and scrap; packaging, un-packaging, mixing/blending and weighing of metal powders or other minerals
PROC 27a	Production of metal powders (hot processes)
	Production of metal powders by hot metallurgical processes (atomisation, dry dispersion)
PROC 27b	Production of metal powders (wet processes)
	Production of metal powders by wet metallurgical processes (electrolysis, wet dispersion)

A2. Descriptors by Sectors of Use

DESCRIPTOR	SECTORS OF USE (SU):
SU 1	Agriculture, forestry, fishery
SU2a	Mining, (without offshore industries)
SU2b	Offshore industries
SU4	Manufacture of food products
SU5	Manufacture of textiles, leather, fur
SU6a	Manufacture of wood and wood products
SU6b	Manufacture of pulp, paper and paper products
SU7	Printing and reproduction of recorded media
SU8	Manufacture of bulk, large scale chemicals (including petroleum products)
SU9	Manufacture of fine chemicals
SU10	Formulation [mixing] of preparations and/or re-packaging (excluding alloys)
SU11	Manufacture of rubber products
SU12	Manufacture of plastics products, including compounding and conversion
SU13	Manufacture of other non-metallic mineral products, e.g. plasters, cement
SU14	Manufacture of basic metals, including alloys
SU15	Manufacture of fabricated metal products, except machinery and equipment
SU16	Manufacture of computer, electronic and optical products, electrical equipment
SU17	General manufacturing, e.g. machinery, equipment, vehicles, other transport equipment
SU18	Manufacture of furniture
SU19	Building and construction work
SU20	Health services
SU21	Consumer uses: Private households (= general public = consumers)
SU22	Professional uses: Public domain (administration, education, entertainment, services, craftsmen)
SU23	Electricity, steam, gas water supply and sewage treatment
SU24	Scientific research and development
SU0	Other

A3. Descriptors by Chemical Product Category

DESCRIPTOR	CHEMICAL PRODUCT CATEGORY (PC)
PC1	Adhesives, sealants
PC2	Adsorbents
PC3	Air care products
PC4	Anti-Freeze and de-icing products
PC5	Non Defined by ECHA
PC6	Non Defined by ECHA
PC7	Base metals and alloys
PC8	Biocidal products (e.g. Disinfectants, pest control)
PC9a	Coatings and paints, thinners, paint removers
PC9b	Fillers, putties, plasters, modelling clay
PC9c	Finger paints
PC10	Non Defined by ECHA
PC11	Explosives
PC12	Fertilizers
PC13	Fuels
PC14	Metal surface treatment products,
PC15	Non-metal-surface treatment products

PC16	Heat transfer fluids
PC17	Hydraulic fluids
PC18	Ink and toners
PC19	Intermediate
PC20	Products such as ph-regulators, flocculants, pre-cipitants, neutralization agents
PC21	Laboratory chemicals
PC22	Non Defined by ECHA
PC23	Leather tanning, dye, finishing, impregnation and care products
PC24	Lubricants, greases, release products
PC25	Metal working fluids
PC26	Paper and board dye, finishing and impregnation products
PC27	Plant protection products
PC28	Perfumes, fragrances
PC29	Pharmaceuticals
PC30	Photo-chemicals
PC31	Polishes and wax blends
PC32	Polymer preparations and compounds
PC33	Semiconductors
PC34	Textile dyes, finishing and impregnating products;
PC35	Washing and cleaning products
PC36	Water softeners
PC37	Water treatment chemicals
PC38	Welding and soldering products (with flux coatings or flux cores.), flux products
PC39	Cosmetics, personal care products
PC40	Extraction agents
PC0	Other

A4. Descriptors by Environmental Release Categories

DESCRIPTOR	ENVIRONMENTAL RELEASE CATEGORIES (ERC)
ERC1	Manufacture of substances
	Manufacture of organic and inorganic substances in chemical, petrochemical, primary metals and minerals industry including intermediates, monomers using continuous processes or batch processes applying dedicated or multi-purpose equipment, either technically controlled or operated by manual interventions
ERC2	Formulation of preparations
	Mixing and blending of substances into (chemical) preparations in all types of formulating industries, such as paints and do-it-yourself products, pigment paste, fuels, household products (cleaning products), lubricants, etc.
ERC3	Formulation in materials
	Mixing or blending of substances which will be physically or chemically bound into or onto a matrix (material) such as plastics additives in master batches or plastic compounds. For in-stance a plasticizers or stabilizers in PVC master-batches or products, crystal growth regulator in photographic films, etc.
ERC4	Industrial use of processing aids in processes and products, not becoming part of articles
	Industrial use of processing aids in continuous processes or batch processes applying dedicated or multi-purpose equipment, either technically controlled or operated by manual interventions. For example, solvents used in chemical reactions or the ‘use’ of solvents during the application of paints, lubricants in metal working fluids, anti-set off agents in polymer moulding/casting.

ERC5	Industrial use resulting in inclusion into or onto a matrix
	Industrial use of substances as such or in preparations (non-processing aids), which will be physically or chemically bound into or onto a matrix (material) such as binding agent in paints and coatings or adhesives, dyes in textile fabrics and leather products, metals in coatings applied through plating and galvanizing processes. The category covers substances in articles with a particular function and also substances remaining in the article after having been used as processing aid in an earlier life cycle stage (e.g. heat stabilisers in plastic processing).
ERC6a	Industrial use resulting in manufacture of another substance (use of intermediates)
	Use of intermediates in primarily the chemical industry using continuous processes or batch processes applying dedicated or multi-purpose equipment, either technically controlled or operated by manual interventions, for the synthesis (manufacture) of other substances. For instance, the use of chemical building blocks (feedstock) in the synthesis of agrochemicals, pharmaceuticals, monomers, etc.
ERC6b	Industrial use of reactive processing aids
	Industrial use of reactive processing aids in continuous processes or batch processes applying dedicated or multi-purpose equipment, either technically controlled or operated by manual interventions. For example, the use of bleaching agents in the paper industry.
ERC6c	Industrial use of monomers for manufacture of thermo-plastics
	Industrial use of monomers in the production of polymers, plastics (thermoplastics), polymerization processes. For example, the use of vinyl chloride monomer in the production of PVC.
ERC6d	Industrial use of process regulators for polymerisation processes in production of resins, rubbers, polymers
	Industrial use of chemicals (cross-linking agents, curing agents) in the production of thermosets and rubbers, polymer processing. For instance, the use of styrene in polyester production or vulcanization agents in the production of rubbers
ERC7	Industrial use of sub-stances in closed systems
	Industrial use of substances in closed systems. Use in closed equipment, such as the use of liquids in hydraulic systems, cooling liquids in refrigerators and lubricants in engines and di-electric fluids in electric transformers and oil in heat exchangers. No intended contact between functional fluids and products foreseen, and thus low emissions via waste water and waste air to be expected.
ERC8a	Wide dispersive indoor use of processing aids in open systems
	Indoor use of processing aids by the public at large or professional use. Use (usually) results in direct release into the environment/sewage system, for example, detergents in fabric washing, machine wash liquids and lavatory cleaners, automotive and bicycle care products (polishes, lubricants, de-icers), solvents in paints and adhesives or fragrances and aerosol propellants in air fresheners.
ERC8b	Wide dispersive indoor use of reactive substances in open systems
	Indoor use of reactive substances by the public at large or professional use. Use (usually) results in direct release into the environment, for example, sodium hypochlorite in lavatory cleaners, bleaching agents in fabric washing products, hydro-gen peroxide in dental care products.
ERC8c	Wide dispersive indoor use resulting in inclusion into or onto a matrix
	Indoor use of substances (non-processing aids) by the public at large or professional use, which will be physically or chemically bound into or onto a matrix (material) such as binding agent in paints and coatings or adhesives, dyeing of textile fabrics
ERC8d	Wide dispersive outdoor use of processing aids in open systems

	Outdoor use of processing aids by the public at large or professional use. Use (usually) results in direct release into the environment, for example, automotive and bicycle care products (polishes, lubricants, de-icers, detergents), solvents in paints and adhesives.
ERC8e	Wide dispersive outdoor use of reactive substances in open systems
	Outdoor use of reactive substances by the public at large or professional use. Use (usually) results in direct release into the environment, for example, the use of sodium hypochlorite or hydrogen peroxide for surface cleaning (building materials)
ERC8f	Wide dispersive outdoor use resulting in inclusion into or onto a matrix
	Outdoor use of substances (non-processing aids) by the public at large or professional use, which will be physically or chemically bound into or onto a matrix (material) such as binding agent in paints and coatings or adhesives.
ERC9a	Wide dispersive indoor use of substances in closed systems
	Indoor use of substances by the public at large or professional (small scale) use in closed systems. Use in closed equipment, such as the use of cooling liquids in refrigerators, oil-based electric heaters.
ERC9b	Wide dispersive outdoor use of substances in closed systems
	Outdoor use of substances by the public at large or professional (small scale) use in closed systems. Use in closed equipment, such as the use of hydraulic liquids in automotive suspension, lubricants in motor oil and break fluids in automotive brake systems.
ERC10a	Wide dispersive outdoor use of long-life articles and materials with low release
	Low release of substances included into or onto articles and materials during their service life in outdoor use, such as metal, wooden and plastic construction and building materials (gutters, drains, frames, etc.)
ERC10b	Wide dispersive outdoor use of long-life articles and materials with high or in-tended release (including abrasive processing)
	Substances included into or onto articles and materials with high or intended release during their service life from outdoor use. Such as tyres, treated wooden products, treated textile and fabric like sun blinds and parasols and furniture, zinc anodes in commercial shipping and pleasure craft, and brake pads in trucks or cars. This also includes releases from the article matrix as a result of processing by workers. These are processes typically related to PROC 21, 24, 25, for example: Sanding of buildings (bridges, facades) or vehicles (ships).
ERC11a	Wide dispersive indoor use of long-life articles and materials with low release
	Low release of substances included into or onto articles and materials during their service life from indoor use. For example, flooring, furniture, toys, construction materials, curtains, foot-wear, leather products, paper and cardboard products (magazines, books, news paper and packaging paper), electronic equipment (casing).
ERC11b	Wide dispersive indoor use of long-life articles and materials with high or intended release (including abrasive processing)
	Substances included into or onto articles and materials with high or intended release during their service life from indoor use. For example: release from fabrics, textiles (clothing, floor rugs) during washing. This also includes releases from the article matrix as a result of processing by workers. These are processes typically related to PROC 21, 24, 25. For example removal of indoor paints.
ERC12a	Industrial processing of articles with abrasive techniques (low release)
	Substances included into or onto articles and materials are re-leased (intended or not) from the article matrix as a result of processing by workers. These processes are typically related to PROC 21, 24, 25. Processes where the removal of material is intended, but the expected release remains low, include for ex-ample: cutting of textile, cutting, machining or grinding of metal or polymers in engineering industries.

ERC12b	Industrial processing of articles with abrasive techniques (high release)
	Substances included into or onto articles and materials are re-leased (intended or not) from/with the article matrix as a result of processing by workers. These processes are typically related to PROC 21, 24, 25. Processes where the removal of material is intended, and high amounts of dust may be expected, includes for example: sanding operations or paint stripping by shot-blasting.

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