



Environmental, Health and Safety (EHS) Impacts

Technology Sector Evaluation:
Chemistry & Materials

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V 1.0 - October 2010

<http://www.observatorynano.eu/>

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1. Introduction

The chemistry and materials sector is rapidly moving from knowledge-based discovery to application orientation according to industry needs. Its output spans all major industries in Europe, including energy, biomedical, environmental and transport sectors. As the number of nanomaterials available for use increases, it is predicted that these may be formed into 'libraries' of nanomaterials and manufacturing methods in the future, which allow for the design of materials tailor-made for specific applications, produced from well characterised and biocompatibility tested materials.

The chemistry and materials sector technical sector report² provides an overview on processing technologies and applications for carbon-based nanomaterials, nanocomposites, nanostructured metals and alloys, nano-polymers and nano-ceramics.

The Environment, Health & Safety analysis of the chemistry and materials technology sector considers the nanomaterials outlined therein within the context of their application, and provides commentary on the exposure potential for the material in question.

The present report covers four major sub-sectors, classified within the ObservatoryNANO technology sector report according to application and societal needs as follows:

- carbon-based nanomaterials
- nanocomposites
- nanostructured metals and alloys
- nano-polymers
- nano-ceramics

A lack of exposure data across all nanoparticle applications is a recognised missing. As the ObservatoryNANO Project progresses, it is expected that this knowledge gap will be addressed (at least in part). This, coupled with additional information on nanomaterial toxicology should enable later EHS reports to reach more resolute conclusions on the risks posed by those nanomaterials in consideration.

2. General Considerations for the Environment, Health & Safety Impact of nanomaterials

The key benefit from nanotechnologies is the ability to exploit the specific, novel and sometimes unpredictable properties that arise from structuring matter at this scale. Over the last 10 years, nanotechnologies have received extensive investment, and have emerged as major drivers of science based innovation and industry. This has led to the development of new processes, products and materials for a wide range of applications.

In 2004 the UK's Royal Society and the Royal Academy of Engineering (RS/RAEng) published a seminal review of the "opportunities and uncertainties" presented by nanotechnologies (RS/RAEng, 2004). Whilst indicating that for many nanotechnologies, there were no foreseeable risks to health or to the environment, the report concluded that for "nanoparticles and nanotubes" there were potential risks, and that not enough was known about them. This conclusion was based on evidence gained from many years of research that exposure to particles can cause ill health within individuals or exposed populations. For example, within the occupational setting, exposure to coal dust is evidentially linked to the onset of lung diseases including pneumoconiosis and chronic obstructive pulmonary disease (COPD), and exposure to asbestos is causative of asbestosis, mesothelioma and lung cancer. In an environmental context, evidence suggests that exposure to the particulate component of atmospheric pollution may be associated with increased hospitalisation rates and cardio-vascular disease (Seaton et. al, 2009).

Publication of the RS/RAEng report led to a huge increase in research activity concerning both human health and environmental consequences (Aitken et. al., 2009a). For example, in Europe the Framework 7 NMP programme has funded more than 20 major projects, with a total budget of more than €50million. This research activity has addressed *inter alia* the toxicity and ecotoxicity of many types of nanoparticles, the kinetics of nanoparticles within biological and environmental systems, the extent to which individuals or the environment can become exposed and the level of risk which would result. These investigations have examined numerous mechanisms, end points and processes and materials, and have generated an extensive body of literature, particularly in relation to toxicology and ecotoxicology.

2.1 Establishing a knowledge on the potential hazard and exposure to nanomaterials

Scientific data compiled to date demonstrates that adverse health effects due to exposure to nanoparticles cannot be ruled out (Aitken et. Al., 2009a; 2009b; van Zijverden & Sips (eds.), 2009). However, although awareness for the importance of risk research has increased, critical information still is lacking to enable estimation of the risks posed by nanoparticles with equal certainty to those of other non-nano substances. Nevertheless, hundreds of products containing nanomaterials are currently available commercially, a situation which clearly necessitates investigation of the exposure and toxicity of these materials in the near future. Unfortunately, the research questions to be answered are so numerous that it will take years to compile the relevant data.

The potential for nanoparticles to cause damage has also been implicated within the environment, both directly via uptake into plants or organisms (including soil bacteria, eukaryotes, invertebrates and vertebrate species), and indirectly via changes in environmental variables such as pH of aquatic systems, ionic strength or dissolved organic carbon content (Aitken et. al., 2009a). Carbon nanotubes (CNT) and silver nanoparticles have been shown to cause detrimental effects in zebrafish development (Cheng et. al., 2007), and copper nanoparticles have been shown to be highly toxic to fish, daphnids and algae (Griffitt et. al., 2008), and to induce stunting of exposed plant seedlings (Lee et. al., 2008).

Man and the environment can come into contact with the use of nanotechnology through a wide range of application areas. Some of these applications are produced only with the aid of nanotechnology, others contain nanomaterials. For the risk assessor, this second category is important, particularly when the applications contain non-degradable, insoluble, and freely available nanoparticles. For this category of products there are already a great many different areas of potential use, including medical applications, food, and consumer products as well as environmental and energy technology. These applications can improve the quality of life and the environment and can also lead to significantly more sustainable products, but for which it is of particular importance to understand and control potential risk.

There are already hundreds of nanotechnology applications on the market. For example, nanoparticles of titanium oxide and zinc oxide are regularly used as UV reflectors in sunscreen creams. Nanotechnology is also used to make clothing crease- and dirt-resistant, and to make electronics ever smaller, faster and more multifunctional. However, the majority of potential applications for nanotechnologies are currently still in the research and development phase and are expected to appear on the market over the coming years.

Understanding and effective management of potential risks posed by manufactured nanoparticles and nanomaterials is pivotal for responsible and sustainable development of nanotechnology. This in turn is mandatory for societal acceptance and exploiting the significant economic potential of this technology to the full.

2.2 Risk Assessment considerations for nanomaterials

In assessing the risks of non-nano chemical substances and nanomaterials alike, the following general approach is applied:

$$RISK = HAZARD (TOXICITY) \times EXPOSURE$$

The intrinsic hazard (toxicity) of a nanomaterial is determined by a number of factors, such as the ability of a nanoparticle to pass through certain barriers in humans, plants or animals and cause damaging effects. The actual exposure is also determined by various factors such as the form in which the nanomaterial occurs (e.g., either bonded or as 'free' particles) the specific setting in which the nanoparticle is being manufactured applied or used (and thus likelihood of contact). Thus, a specific nanomaterial may be hazardous, but if the level of exposure is very small, the ultimate risk will always be limited. For example, a specific nanoparticle bound within ultra-high performance concrete used to construct a bridge will pose less of a potential risk to consumers (i.e. those using the bridge), than the same NP used within antimicrobial food packaging, where the potential for consumer exposure may be increased due to their close contact with the product in which the NPs are bound.

Two areas can be distinguished within risk research for nanotechnology. One area aims at risks related to exposure to nanomaterials and the second area aims at risks related to the rest of nanotechnology and its products. There is consensus that the uncertainties about these risks need to be addressed most urgently.

In 2009, the Dutch Knowledge and Information Point "Risks of Nanotechnology" (RIVM/KIR nano) recommended to focus research primarily on those questions that provide information critical to the assessment of risks to man and the environment (van Zijverden & Sips (eds.), 2009). Depending on the perspective - worker, consumer, patient, or the environment - the starting points can then be defined for controlling or limiting the risks.

From this and other literature on the topic, there may be identified several key challenges for the EHS appraisal and risk management of nanomaterials:

1. *There is a high urgency for relevant risk information:* One of the pitfalls of emerging technologies is the imbalance between technological development and attention for human health and environmental safety issues as is the case for

nanotechnology. Risk information needs to be generated and shared as quickly as possible for products on the market, underpinning the societal acceptance of further applications of this technology.

2. *Validity of known test systems is questionable, and detection of nanomaterials still problematic.* Nanomaterials create a challenge for risk research as they (might) behave differently in regular assessment and testing systems. Equipment and methods to detect nanomaterials allowing large-scale application are lacking.
3. *National, international and interdisciplinary integration is a prerequisite.* A large variety of research questions need to be addressed before uncertainties about risks for man and the environment are at the same level as for other chemical substances.

Whilst this brief introduction provides an outline of the key issues, it is impossible to outline the current knowledge on the hazard, exposure and risk assessment for nanoparticles in full. Instead the reader is directed towards the ObservatoryNANO Baseline Studies (Ross et. al., 2009) where many of the seminal studies from the last few years are identified and described.

2.3 The ObservatoryNANO Approach: Integrating EHS considerations with development of novel applications for nanotechnologies

ObservatoryNANO is concerned with mapping scientific and technological development across 10 core technology sectors, and a key task of WP5 is to undertake an appraisal of these reports and to identify potential emerging environment, health and safety issues therein, thus integrating the development of novel applications with risk research, an approach which is urgently required.

There is considerable overlap between those nanoparticles used across these 10 sectors - what differs is their use, which varies according to the application. Therefore the aspect which is specific to the technical sector in considering those novel risks which may arise from development of novel applications, is the potential for exposure. For this reason, the approach which we have adopted is to consider the potential exposure which may arise from the new applications identified.

As far as possible, we have considered the life cycle of the applications identified, whether there were possible exposures within the occupational setting, or to consumers or release to the environment. We also considered whether there was the potential for release from disposal.

Our review process involved extraction of information from each technology sector report & gathering of additional information from their lead authors. This data was then analysed, and our findings outlined within the subsequent sections of this report. In addition to a short summary of the key exposure issues identified from our analysis, our report includes three key tables as follows:

1. A table summarising all information gathered together with consideration of the potential for exposure arising throughout the lifecycle of each application
2. A table outlining those nanoparticles/nanomaterials in use within each technology sector, according to application
3. A table highlighting those applications where we consider there to be a high potential for release.

Detailed information of the type required to make strong evidence judgments about possible exposures was only very rarely available, and this is indicated in table. In none of the scenarios was actual exposure data available. However, for some applications additional information was available from the peer reviewed literature, and where this has been used this is again indicated within the table. In the majority on settings identified, due to the paucity of data assessment of whether or not exposure is plausible is based on expert judgement and information available from other similar scenarios. In this respect, these judgements should be considered provisional and where possible, effort should be

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placed on collecting relevant specific primary exposure data. As the ObservatoryNANO Project progresses, it is expected that these knowledge gaps will be addressed (at least in part) and thus that later EHS reports will be able to reach more resolute conclusions on the risks posed by those nanomaterials in consideration.

3. Potential for exposure

The following table outlines and ranks the *potential* for exposure associated with the use of nanomaterials in the applications shown. In the absence of real exposure data, it is based primarily upon expert evaluation of the information provided in the technical reports. As a default we have indicated that there is a high potential for exposure in all occupational settings associated with the manufacture of nanomaterials unless adequate control measures are applied. In applications where the hazard (toxicity) of the nanomaterials is similar, those with the highest potential exposure will have the highest potential risks.

Table 1: Potential exposure in applications

Application & NP - Basic Info		CHEMISTRY & MATERIALS Sector - Carbon Based NMs						Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, Sewage Treatment Plant)		Application Devt. Stage
		Exposure potential - Use (e.g. activity, exposure route, what)			Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, Sewage Treatment Plant)					
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
Carbon-based NMs	3.2.2	Carbon Black	controlled incomplete combustion of hydrocarbons	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combustion	Established on the market
	3.2.2	Carbon Black	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small unless via cutting/manipulation at installation	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combustion	Established on the market
	3.2.2	Carbon Black	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal/inhalation exposure possible	medium - release into air during printing process shown (Hänninen et al, 2010)	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combustion	Established on the market

Application & NP - Basic Info		CHEMISTRY & MATERIALS Sector - Carbon Based NMs						Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, Sewage Treatment Plant)		Application Devt. Stage
		Exposure potential - Use (e.g. activity, exposure route, what)						Human	Environment	
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.2.2	Filler in compound materials	C60 Fullerene	laser evaporation process of graphite	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small unless via cutting/manipulation at installation	Low - exposure potential very small unless via abrasion	Low - exposure potential very small unless via abrasion	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combustion	Established on the market
3.2.2	Friction minimising additive in lubricants	C60 Fullerene	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small unless via abrasion	Low - exposure potential very small unless via abrasion	Low - exposure potential very small unless via abrasion	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combustion	not on market - other NPs overtook this for suitability
3.2.2	Solar Cells	C60 Fullerene	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small unless via abrasion	Low - exposure potential very small unless via abrasion	Low - exposure potential very small unless via abrasion	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combustion	R&D stage
3.2.2	Biomedical - tracer in imaging diagnostics	C60 Fullerene	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	High - used within the human body	Low - very small quantities, higher exposure only if enters environment via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - quantities requiring disposal likely to be very small	R&D stage
3.2.2	Biomedical - protein marker	C60 Fullerene	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	High - used within the human body	Low - very small quantities, higher exposure only if enters environment via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - quantities requiring disposal likely to be very small	R&D stage

Application & NP - Basic Info		CHEMISTRY & MATERIALS Sector - Carbon Based NMs							Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, Sewage Treatment Plant)		Application Devt. Stage
		Exposure potential - Use (e.g. activity, exposure route, what)							Human	Environment	
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment		
3.2.2	Biomedical - Drug Delivery System	C60 Fullerene	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	High - used within the human body	Low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	medium - release possible via entry to wastewater stream or from sewage treatment plant (STP)	R&D stage	
3.2.2	Pigment Production	Graphite NPs	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible	Medium - release during printing, or from wear and tear/friction on clothes	Low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Established on the market	
3.2.2	Additive in rubber and plastic products	Graphite NPs	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small unless via cutting/manipulation at installation	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combu stion	Established on the market	
3.2.2	Electrode materials in e.g. batteries	Graphite NPs	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combu stion	Established on the market	
3.2.2	Hydrogen storage	Graphite NPs	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - exposure possible if top-up of fuel cells is required	Low - exposure potential very small unless via accidental release	Low - exposure potential very small unless via accidental release	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible during disposal process	Early R&D	

CHEMISTRY & MATERIALS Sector - Carbon Based NMs										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)					Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, Sewage Treatment Plant)		Application Dev't. Stage
Sub sector ¹	Application ²	Types of NP ³	Incorporati on in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.2.2	Nanoelectronic Transistors	CNTs	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combu stion	R&D stage
3.2.2	Data Storage (see also Memory/NRAM in ICT sector report)	CNTs	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combu stion	R&D stage
3.2.2	Electron Emitters in flat panel displays	CNTs	Dependent on type of display (see ICT report)	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combu stion	R&D stage
3.2.2	electrode materials	CNTs	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combu stion	R&D stage
3.2.2	fillers for anti- static and conductive plastic composites	CNTs	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combu stion	R&D stage

Application & NP - Basic Info		CHEMISTRY & MATERIALS Sector - Carbon Based NMs							Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, Sewage Treatment Plant)		Application Devt. Stage
		Exposure potential - Use (e.g. activity, exposure route, what)							Human	Environment	
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment		
3.2.2	electrode materials in electrochemical applications	CNTs	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combustion	R&D stage	
3.2.2	Biomedical - compound tracers	CNTs	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	medium / high - used within the human body	Low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	R&D stage - biocompatibility and toxicity being investigated	
3.2.2	Biomedical - drug-delivery systems	CNTs	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	High - used within the human body	Low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	medium - release possible via entry to wastewater stream or from stp	R&D stage - biocompatibility and toxicity being investigated	
3.2.2	electrodes in electrochemical applications	Nanohorns	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combustion	R&D	
3.2.2	Tribiological applications	Carbon Films	Chemical Vapour Deposition & PVD in a vacuum	High - Release during manufacture is possible, exposure predominantly via air	Medium - exposure possible if cutting/manipulation required at installation	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	Applied in tribiological applications	

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CHEMISTRY & MATERIALS Sector - Carbon Based NMs										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)				Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, Sewage Treatment Plant)		Application Devt. Stage	
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.2.2	Friction lowering and wear maximising coating	Diamond-like Carbon	Chemical Vapour Deposition	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small unless via cutting/manipulation at installation	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	Applied on market?
3.2.2	Coatings	Covalent Carbides e.g. SiC, B ₄ C, TiC & LaC ₂	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small unless via cutting/manipulation at installation	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	R&D
3.2.2	Reinforcing filler in composite materials	Graphene	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - exposure possible via cutting/manipulation at installation	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combustion	R&D
3.2.2	Electronics	Graphene	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - nanoparticles bound in matrix	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	R&D
3.2.2	Electrode materials in electrochemical applications	Carbon Aerogels	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - potential for exposure during installation as materials is very friable	Low - exposure potential very small unless via accidental disturbance of friable material	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combustion	R&D

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Application & NP - Basic Info		CHEMISTRY & MATERIALS Sector - Carbon Based NMs						Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, Sewage Treatment Plant)		Application Devt. Stage
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.2.2	Thermal Insulation	Carbon Aerogels	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - potential for exposure during installation as materials is very friable	Low - exposure potential very small unless via accidental disturbance of friable material	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/combustion	R&D
3.2.2	Solar Energy Collectors	Carbon Aerogels	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - potential for exposure during installation as materials is very friable	Low - exposure potential very small unless via accidental disturbance of friable material	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding	R&D

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CHEMISTRY & MATERIALS Sector - Nanocomposites										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)					Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage
Sub sector ¹	Application ²	Types of NP ³	Incorporati on in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.3	Food packaging	Polymer- nanoclay composites	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix so exposure unlikely unless they are released	Low - nanoparticles bound in matrix so exposure unlikely unless they are released	Low - nanoparticles bound in matrix	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/com bustion	Advanced applied state
3.3	Lightweight construction	polymer matrix nanocompo sites (POSS)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible if in liquid/slurry form	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Market entry within 5 years
3.3	Heat- resistant materials	polymer matrix nanocompo sites (POSS)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/com bustion	Market entry within 5 years
3.3	Flame resistant additives	polymer matrix nanocompo sites (POSS)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Med - exposure potential via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/com bustion	Market entry within 5 years

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CHEMISTRY & MATERIALS Sector - Nanocomposites										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)					Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage
Sub sector ¹	Application ²	Types of NP ³	Incorporati on in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.3	Nano fillers for MMCs (various apps e.g. lightweight construction), tribiological coatings	Metal Matrix Composites e.g. tungsten carbide NPs embedded in Co matrix)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/ combustion	Marketed
3.3	Ceramic matrix materials containing nanoscale carbon fillers with improved electrical conductivity and mechanical robustness	Nanoscale carbon fillers (e.g. CNT, fullerenes, Carbon nanofibres)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/ combustion	In R&D stage
3.3	Wear and Heat-resistant coatings (e.g. for medical implants)	Metal ceramic nanocompo sites	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Medium / high - used within the human body	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Marketed
3.3	Lubricants in biomedical applications	Metal ceramic nanocompo sites	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	Medium / high - used within the human body	Low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	5-10 years to market entry

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CHEMISTRY & MATERIALS Sector - Nanocomposites										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)					Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage
Sub sector ¹	Application ²	Types of NP ³	Incorporati on in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.3	Transport (coatings)	Metal ceramic nanocompo sites	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/com bustion	Marketed
3.3	Catalysts	Metal ceramic nanocompo sites	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Marketed
3.3	Coatings for Machine tools	Metal ceramic nanocompo sites	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Marketed
3.3	Bio-medical diagnostics	Quantum Dots (core- shell nanocrystal s)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	medium / high - used within the human body	Low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Advanced Research state

CHEMISTRY & MATERIALS Sector - Nanocomposites										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)					Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage
Sub sector ¹	Application ²	Types of NP ³	Incorporati on in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.3	Electronics	Quantum Dots (core-shell nanocrystals)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Advanced Research state
3.3	Seal coatings for vehicle & aircraft bodies	Quantum Dots (core-shell nanocrystals)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Advanced Research state
3.3	Food analytics	Quantum Dots (core-shell nanocrystals)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Advanced Research state
3.3	Electro-magnetic insulation	Quantum Dots (core-shell nanocrystals)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	Advanced Research state

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CHEMISTRY & MATERIALS Sector - Nano Metals & Alloys										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)				Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage	
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.4	Ferromagnetic properties - ferrofluid or magnetic data storage	Cobalt	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Early Applied Research
	Alloy compounds to steel	Titanium	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	Marketed
	Biomedical - implants	Titanium	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible during handling /implant	medium / high - used within the human body	Low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Marketed
	Optical detection & sensing in analytical chemistry	Noble metals - e.g. Au, Ag, Pt & Pd	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Under R&D
	Nano Metals & Alloys									

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CHEMISTRY & MATERIALS Sector - Nano Metals & Alloys										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)					Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage
Sub sector ¹	Application ²	Types of NP ³	Incorporati on in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.4	Imaging - diagnostics & molecular biology	Noble metals - Au, Ag, Pt & Pd	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	medium / high - used within the human body	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Advanced Applied Research, some marketed
3.4	Biomedical - implants & diagnostics (antibacteria l)	Noble metals - Au	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	medium / high - used within the human body	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Marketed
3.4	Drug devt & delivery	Noble metals - Ag, Au & Pt	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	medium / high - used within the human body	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Marketed
3.4	Biomedical - Imaging diagnostics	Noble metals - Au	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	medium / high - used within the human body	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Marketed
3.4	Bio-labelling & detection	Noble metals - Ag	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	medium / high - used within the human body	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Marketed

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CHEMISTRY & MATERIALS Sector - Nano Metals & Alloys										
Application & NP - Basic Info			Exposure potential (- Use (e.g. activity, exposure route, what)				Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage	
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.4	Catalytic Converters	Noble metals - Au	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Marketed
3.4	Hydrogen Catalysts	Noble metals - Pt	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Marketed
3.4	Solar Cells	Noble metals e.g. Au	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Marketed
3.4	Ink & pigment additives	Noble metals - Ag	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal/inhalation exposure possible	medium - release into air during printing process shown	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/com bustion	Marketed
3.4	Medical Implants	Al nanopowder	Spray atomisation is most common	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix, but medium if implant being manipulated in any way e.g. re-shaping	Medium / high - used within the human body	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Marketed

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CHEMISTRY & MATERIALS Sector - Nano Metals & Alloys										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)				Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage	
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.4	Transport and energy applications	Al nanopowder	Spray atomisation is most common	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	R&D stage
3.4	Powder Metallurgy e.g. sintering	Metal Nanopowders e.g. Mg, Ni, Ti, Fe, Cr & Co	Spray atomisation is most common	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	R&D stage 5years + to market
3.4	Coating technologies	Metal Nanopowders e.g. Al, Mg, Ni, Ti, Fe, Cr, Co	Spray atomisation is most common	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Marketed - biomed implants and coatings
3.4	Hydrogren storage	Mg-Ni Alloys	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - exposure possible if top-up of fuel cells is required	Low - exposure potential very small unless via accidental release	Low - exposure potential very small unless via accidental release	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible during disposal process	R&D stage
3.4	ICT (magnetic datastorage)	Ferromagnetic NPs (e.g. Co)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Early Applied Research

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CHEMISTRY & MATERIALS Sector - Nano Metals & Alloys										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)				Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage	
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.4	Ferrofluids in Medical diagnostics	Ferromagnetic NPs	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	Medium / high - used within the human body	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Early Applied Research
3.4	Ferrofluids in e.g. vehicle suspension & braking systems	Ferromagnetic NPs	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium/High - dermal exposure possible by accidental release	Low - exposure unlikely unless via accidental spillage	Low - exposure unlikely unless via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium/High - release possible via entry to wastewater stream or from stp	R&D stage
3.4	Hydrogen Storage	Metal hydrides	high energy milled	High - Release during manufacture is possible, exposure predominantly via air	Medium - exposure possible if top-up of fuel cells is required	Low - exposure potential very small unless via accidental release	Low - exposure potential very small unless via accidental release	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible during disposal process	R&D stage
3.4	Hydrogen Storage	Nanocrystalline magnesium furtheron	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - exposure possible if top-up of fuel cells is required	Low - exposure potential very small unless via accidental release	Low - exposure potential very small unless via accidental release	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible during disposal process	R&D stage
3.4	lightweight construction & aero/auto	Nanocrystalline Al	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Applied research 5yrs to market

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CHEMISTRY & MATERIALS Sector - Nano Metals & Alloys										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)				Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage	
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.4	lightweight construction & aero/auto	Nanocrystalline Mg	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Applied research 5yrs to market
3.4	Medical implants	Nanocrystalline Ti	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible during implantation	medium / high - used within the human body	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Applied research 5yrs to market
3.4	lightweight construction & aero/auto	Nanocrystalline Ti	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Applied research 5yrs to market
3.4	lightweight construction & aero/auto	Nanocrystalline Ti-Al Alloy	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Applied research
3.4	Electro-mechanical systems	Nanocrystalline Ti-Ni Alloy	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	R&D stage

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CHEMISTRY & MATERIALS Sector - Nano Metals & Alloys										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)				Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage	
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.4	Electronic Engineering applications	Nanocrystalline Fe-Cu-Nb-Si-B alloys	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	Marketed
3.4	mechanical components for transport and biomedical applications	Nanocrystalline high grade steel	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix, but medium if implant being manipulated in any way e.g. re-shaping	Medium / high - used within the human body	Low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Applied research 5yrs to market
3.4	Optical applications e.d. sensors, cameras, solar cells, LEDs etc.	Plasmonic Nanostructures	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	R&D stage 10+ years to market

CHEMISTRY & MATERIALS Sector - Nano Polymers											
Application & NP - Basic Info				Exposure potential - Use (e.g. activity, exposure route, what)				Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage	
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment		
Nano Polymers	3.5	Polymer nanostructures	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix, but medium if implant being manipulated in any way e.g. re-shaping	Medium / high - used within the human body	Low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	R&D	
	3.5	Polymer nanostructures	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	High - used within the human body	low - very small quantities, higher exposure only if enters into environment via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - quantities requiring disposal likely to be very small	basic research stage	
	3.5	Polymer nanostructures	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion / wear & tear	Low - exposure potential very small unless via abrasion / wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing / shredding / combustion	R&D	
	3.5	Polymer nanostructures as electrode and sensor materials	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion / wear & tear	Low - exposure potential very small unless via abrasion / wear & tear	Low - exposure potential very small unless via abrasion / wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing / shredding / combustion	Applied research
	3.5	Nano-membranes for filters	Polymer nanostructures	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion / wear & tear	Low - exposure potential very small unless via abrasion / wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	Applied research
					possible, exposure predominantly via air						

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CHEMISTRY & MATERIALS Sector - Nano Polymers										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)				Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage	
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.5	Biomedical e.g. tissue engineering or the surface design of medical implants	Nano-structured PMMA-films	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix, but medium if implant being manipulated in any way e.g. re-shaping, or if via accidental contact with tissue	Medium / high - used within the human body	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Marketed
3.5	photo resist in micro lithography	Nano-structured PMMA-films	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion / wear & tear	Low - exposure potential very small unless via abrasion / wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	Market entry
3.5	photodectors, field effect transistors and LEDs	Polyacetylene films	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion / wear & tear	Low - exposure potential very small unless via abrasion / wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	Applied research
3.5	chemical and thermal insulation	polystyrene - polyethylene oxide (PEO) films	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion / wear & tear	Low - exposure potential very small unless via abrasion / wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	Applied research

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CHEMISTRY & MATERIALS Sector - Nano Polymers										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)					Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
				via air				release		
3.5	bio-medical surfaces	polystyrene - polyethylene oxide (PS-PEO) films	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal surface manipulated in any way during fitting	Medium - dermal exposure potential if released from coating	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Applied research
3.5	polymer electrolyte batteries	polystyrene - polyethylene oxide (PS-PEO) films	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	Applied research
3.5	biological coatings	Polymer-coatings	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal surface manipulated in any way during fitting	Medium - dermal released from coating due to wear and tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	medium applied research stage with market realizations to be expected towards 2015.
3.5	solar cells / batteries	Polymer-coatings	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	medium applied research stage with market realizations to be expected towards 2015.

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CHEMISTRY & MATERIALS Sector - Nano Polymers										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)					Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.5	Displays	Polymer-coatings	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion / wear & tear	Low - exposure potential very small unless via abrasion / wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	medium applied research stage with market realizations to be expected towards 2015.
3.5	thin film transistors	Polymer-coatings	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion / wear & tear	Low - exposure potential very small unless via abrasion / wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	medium applied research stage with market realizations to be expected towards 2015.
3.5	lubricant coatings	styrene-ethylene-butylene-styrene (SEBS) nanofilms	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion / wear & tear	Low - exposure potential very small unless via abrasion / wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	medium applied research stage with market realizations to be expected towards 2015.

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CHEMISTRY & MATERIALS Sector - Nano Polymers										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)					Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.5	additive to rubber and oil products	Polymer nanoparticles	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix	Low - exposure potential very small unless via abrasion / wear & tear	Low - exposure potential very small unless via abrasion / wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Market entry
3.5	drug delivery systems	poly(allylene glycol) polyethylene glycol nanoparticles (PAB-PDM)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	medium / high - used within the human body	Low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Market entry
3.5	gas sensing	Polymer nanotubes and nanowires	one-dimensional nanostructures formed by Template synthesis (electro)chemical in situ deposition	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion / wear & tear	Low - exposure potential very small unless via abrasion / wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Applied research 5-10yrs to market
3.5	batteries and super capacitors	Polymer nanotubes and nanowires	one-dimensional nanostructures formed by Template synthesis -	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion / wear & tear	Low - exposure potential very small unless via abrasion / wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Applied research 5-10yrs to market

CHEMISTRY & MATERIALS Sector - Nano Polymers										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)					Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage
Sub sector ¹	Application ²	Types of NP ³	Incorporati on in products (electro)ch emical in situ deposition	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.5	molecule transport	Polymer nanotubes and nanowires		High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	medium / high - used within the human body	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Applied research 5- 10yrs to market
3.5	drug delivery	Polymer nanotubes and nanowires		High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	High - used within the human body	low - very small quantities, higher exposure only if enters into environment via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - quantities requiring disposal likely to be very small	Applied research 5- 10yrs to market
3.5	tissue engineering	Polymer nanotubes and nanowires		High - Release during manufacture is possible, exposure predominantly via air	Medium - exposure potential via accidental contact with tissue	Medium / high - used within the human body	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Applied research 5- 10yrs to market
3.5	drug delivery systems	Polymer nanofibers	Not Specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	High - used within the human body	low - very small quantities, higher exposure only if enters into environment via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - quantities requiring disposal likely to be very small	medium applied research stage with market realizations to be expected towards 2015.

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CHEMISTRY & MATERIALS Sector - Nano Polymers										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)				Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage	
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.5	base materials for tissue engineering and bio-medical implants	Dendrimers	Dendrimers are cascade polymers differing from other polymer types.	High - Release during manufacture is possible, exposure predominantly via air	Medium - exposure potential via accidental contact with tissue	Medium / high - used within the human body	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	medium applied research stage with market realizations to be expected towards 2015.
3.5	drug delivery systems	Dendrimers	Dendrimers are cascade polymers differing from other polymer types.	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	High - used within the human body	low - very small quantities, higher exposure only if enters into environment via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - quantities requiring disposal likely to be very small	transition state between basic and applied research
3.5	protein or enzyme modelling	Dendrimers	Dendrimers are cascade polymers differing from other polymer types.	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	High - used within the human body	low - very small quantities, higher exposure only if enters into environment via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - quantities requiring disposal likely to be very small	transition state between basic and applied research
3.5	bio-medical coatings	Dendrimers	Dendrimers are cascade polymers differing from other polymer types.	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal if material onto which coating is applied is manipulated in any way	Medium - dermal exposure potential if released from coating	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	transition state between basic and applied research

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CHEMISTRY & MATERIALS Sector - Nano Polymers										
Application & NP - Basic Info			Exposure potential - Use (e.g. activity, exposure route, what)					Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
					fitting					
3.5	additives to inks and paints	Dendrimers	Dendrimers are cascade polymers differing from other polymer types.	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal/inhalati on exposure possible	medium - release into air during printing process shown	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/com bustion	transition state between basic and applied research
3.5	within OLEDs & solar cells	Dendrimers	Dendrimers are cascade polymers differing from other polymer types.	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	transition state between basic and applied research
3.5	sensors and detectors	Dendrimers	Dendrimers are cascade polymers differing from other polymer types.	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	transition state between basic and applied research

CHEMISTRY & MATERIALS Sector - Nano Ceramics										
Application & NP - Basic Info		Exposure potential - Use (e.g. activity, exposure route, what)					Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage	
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.6 3.6 3.6 3.6	Displays	Indium-Tin oxide (ITO)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	Marketed
	thermal insulation coating on window glass	Indium-Tin oxide (ITO)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	advanced state of applied research
	packing and storage of sensitive electronic components	Indium-Tin oxide (ITO)	thin-film material	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal unless released via crushing /shredding/com bustion	advanced state of applied research
	heat and wear resistant coatings for cutting and grinding tools	Aluminium oxide (Al ₂ O ₃)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal unless released via crushing /shredding/com bustion	Commercialised

CHEMISTRY & MATERIALS Sector - Nano Ceramics

Application & NP - Basic Info		Exposure potential - Use (e.g. activity, exposure route, what)						Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage	
		Manufacturer	Professional user	Consumer	Environment	Human	Environment				
Sub sector ¹	3.6	transparent coatings	Aluminium oxide (Al ₂ O ₃)	Incorporation in products size of about 20 nm and quite high sur-face-volume ratio	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal unless released via crushing /shredding/com bustion	advanced state of applied research
					High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal unless released via crushing /shredding/com bustion	Marketed
	3.6	photo resists in lithography processes	Silicon dioxide (SiO ₂)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal unless released via crushing /shredding/com bustion	Marketed
					High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal unless released via crushing /shredding/com bustion	Marketed
3.6	main base material even for the new material type of aerogels	Silicon dioxide (SiO ₂) in its nanoporous, foam-like form	sol-gel-synthesis	Low - exposure potential very small unless break up of friable aerogel material	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal unless released via crushing /shredding/com bustion	Marketed	

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CHEMISTRY & MATERIALS Sector - Nano Ceramics

Application & NP - Basic Info		Exposure potential - Use (e.g. activity, exposure route, what)						Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.6	insulation and as filter materials	silica aerogels	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal unless released via crushing /shredding/com bustion	Marketed
3.6	lightweight construction	silica aerogels	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small unless via break up of friable aerogel material	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal unless released via crushing /shredding/com bustion	Marketed
3.6	transparent coatings	Titanium oxide nanoparticles	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal unless released via crushing /shredding/com bustion	Advanced state of applied research
3.6	sun screen cosmetics	Titanium oxide nanoparticles	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible	High - applied to the skin	Medium/High - exposure likely, especially into water	Medium - exposure possible at disposal, especially if water treatment does not remove NPs	High - exposure likely, especially via STP/water processing	Marketed

CHEMISTRY & MATERIALS Sector - Nano Ceramics

Sub sector ¹		Application & NP - Basic Info				Exposure potential - Use (e.g. activity, exposure route, what)				Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage
		Application ²	Types of NPs ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment		
3.6	Chemical catalysis applications such as e. g. the photocatalytic purification of water	Titanium oxide nanoparticles	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal unless crushed/shredding/com bustion	Marketed		
	organic solar cells	Titanium oxide nanoparticles	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Advanced state of applied research		
	solar cells	Zinc oxide (ZnO)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low/Medium - release dependant on method of disposal	Marketed		
	liquid crystal displays	Zinc oxide (ZnO)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	Basic research stage		

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CHEMISTRY & MATERIALS Sector - Nano Ceramics

Application & NP - Basic Info		Exposure potential - Use (e.g. activity, exposure route, what)						Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage	
		Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment		Human
3.6	conductive thin-films in blue laser diodes	Zinc oxide (ZnO)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	advanced state of applied research
	UV-filter in commercial sunscreens	Zinc oxide (ZnO)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible	High - applied to the skin	Medium/High - exposure likely, especially into water	Medium - exposure possible at disposal, especially if water treatment does not remove NPs	High - exposure likely, especially via STP/water processing	Marketed	
3.6	protecting surfaces from degeneration by exposure to UV-radiation	Rare-earth oxides (Dy-, Er-, Eu-, Gd-, Nd-, Sm-, Tb-, Yb- and Y-oxides)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/com bustion	Marketed on a small scale
	improve catalytic reactions within catalytic converters on vehicles	Zirconium and cerium oxides	frequently doped with rare-earths such as yttrium.	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	Marketed - small scale

CHEMISTRY & MATERIALS Sector - Nano Ceramics

Application & NP - Basic Info		Exposure potential - Use (e.g. activity, exposure route, what)						Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage
		Sub sector ¹	Application ²	Types of NPs ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	
3.6	Passive and active implants in the bio-medical sector	Zirconium nanoparticles	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix, but medium if implant being manipulated in any way e.g. re-shaping	Medium / high - used within the human body	low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via entry to wastewater stream or from stp	Marketed - large scale use
	pigments for lacquers and paints	Iron oxide nanoparticles	processed by either chemical vapour deposition, sol-gel-processing or flame pyrolysis.	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal/inhalation exposure possible	medium - release into air during printing process shown	Low - exposure only if enters into wastewater or via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/com bustion	Marketed - large scale use
3.6	In medical research e.g. as contrast agents in MRI-tomography or in cancer therapy.	Iron oxide nanoparticles	processed by either chemical vapour deposition, sol-gel-processing or flame pyrolysis.	High - Release during manufacture is possible, exposure predominantly via air	Medium - dermal exposure possible via accidental spillage	High - used within the human body	low - very small quantities, higher exposure only if enters into environment via accidental spillage	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - quantities requiring disposal likely to be very small	advanced state of applied research
3.6	hardening surfaces of cutting machinery	Non-oxide nano-ceramics - tungsten carbide (WZC)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - exposure potential very small unless via abrasion/ wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Low - release unlikely during disposal	Already in use and at the barrier to large scale production

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		CHEMISTRY & MATERIALS Sector - Nano Ceramics								
Application & NP - Basic Info		Exposure potential - Use (e.g. activity, exposure route, what)						Exposure potential - Disposal (e.g. incinerated, landfilled, recycled, STP)		Application Devt. Stage
Sub sector ¹	Application ²	Types of NP ³	Incorporation in products	Manufacturer	Professional user	Consumer	Environment	Human	Environment	
3.6	thermal and mechanical reinforcing or friction lowering coatings	Carbide nano-ceramics (based on e.g. Si, N, B, Ti)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - release only possible via wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/com bustion	Base and applied research
	ball bearings (shock and heat-resistant characteristics)	Nanoparticulate silicon nitride (Si3N4)	Not specified	High - Release during manufacture is possible, exposure predominantly via air	Low - exposure potential very small	Low - exposure potential very small unless via abrasion/ wear & tear	Low - release only possible via wear & tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding/com bustion	Advanced research state

4.0 Conclusions

The key nanoparticles identified as carrying potential EHS impact across the construction technology sector are outlined in tables 2, 3 and 4. Table 2 details carbon-based nanomaterials, table 3 metal and metal-oxide nanoparticles, and table 4 Composite, Polymer & Ceramic -based Nanoparticles. The two most commonly used types within the sector were CNTs, nylon nanocomposites and metal oxides.

Table 2: Carbon-based Nanoparticles carrying potential EHS impact, according to application

	Carbon Black	C60 Fullerene	Graphite NPs	CNTs	Nanohorns	Nanorods	Nanofibers	Carbon Films	Diamond-like Carbon	Covalent Carbides - SiC	Covalent Carbides - B4C	Metallic Carbides - TiC	Metallic Carbides - LaC2	Graphene	Carbon - Nanostructured, Nanoporous, Nanofoams & Aerogels
Antistatic fillers for plastic packaging	•														
Paint & Pigment Production	•														
Pigment Production			•												
Filler Material	•														
Filler in composite materials														•	
Filler in compound materials		•													
Fillers for anti-static and conductive plastic composites				•											
Friction minimising additive in lubricants		•													
Solar Cells		•													
Biomedical - tracer in imaging diagnostics		•													
Biomedical - protein markers		•													
Biomedical - Drug Delivery System		•		•											
Biomedical - compound tracers				•											
Additive in rubber and plastic products			•												
Electrode materials in e.g. batteries			•												
Hydrogen storage			•												

	Carbon Black	C60 Fullerene	Graphite NPs	CNTs	Nanohorns	Nanorods	Nanofibers	Carbon Films	Diamond-like Carbon	Covalent Carbides - SiC	Covalent Carbides - B4C	Metallic Carbides - TiC	Metallic Carbides - LaC2	Graphene	Carbon - Nanostructured, Nanoporous, Nanofoams & Aerogels
Nanoelectronic Transistors			•												
Electron Emitters in flat panel displays			•												
Electrode materials			•												
Electrode materials in electrochemical applications			•												
Electronics					•									•	
Stiff and strong fibres															
Tribological applications								•							
Friction lowering and wear maximising coating									•						
Coatings															
Thermal insulation															•

Table 3: Metal and Metal Oxide -based Nanoparticles carrying potential EHS impact, according to application

	Co - Cobalt	Ti - Titanium	Noble metals - Gold	Noble metals - Silver	Noble metals - Platinum	Noble metals - Lead	Aluminium Nanopowder	Magnesium Nanopowder	Nickel Nanopowder	Titanium Nanopowder	Iron Nanopowder	Chromium Nanopowder	Cobalt Nanopowder	Magnesium-Nickel Alloys	Ferromagnetic NPs	Metal hydrides	Nanocrystalline metals	Nanocrystalline magnesium furtheron	Nanocrystalline Aluminium	Nanocrystalline Magnesium	Nanocrystalline Magnesium-Aluminium Alloy	Nanocrystalline Titanium	Nanocrystalline Titanium-Nickel Alloy	Nanocrystalline Iron-Copper-Nionium-Silicon-Boron alloys	Nanocrystalline high grade steel	Indium-Tin oxide (ITO)	Aluminium oxide (Al ₂ O ₃)	Silicon dioxide (SiO ₂) both in base form or in its nanoporous, foam-like form	Silica aerogels	Titium Dioxide (TiO ₂) nanoparticles	Zinc oxide (ZnO)	rare-earth oxides (Dy-, Er-, Eu-, Gd-, Nd-, Sm-, Tb-,Yb- and Y-oxides)	Zirconium and Cerium oxides	Iron oxide nanoparticles	Non-oxide nano-ceramics - tungsten carbide (W2C)	carbide nano-ceramics (based on e. g. Si, N, B, Ti)	nanoparticulate silicon nitride (Si ₃ N ₄)		
Ferromagnetic properties - ferrofluid or magnetic data storage	•																																						
Alloy compounds to steel		•																																					
Optical detection & sensing in analytical chemistry			•	•	•	•																																	
Biomedical - implants		•																					•																
Imaging - diagnostics & molecular biology			•																																				
Biomedical - implants & diagnostics (antibacterial)			•																																				
Biomedical - Drug devt & delivery			•		•																																		
Biomedical - Imaging diagnostics			•																																				
Bio-labelling & detection			•																																				
Catalytic Converters			•																																				
Hydrogen Catalysts					•																																		
Solar Cells			•																																				

Applications in which potential EHS issues were identified for nanomaterials used within the chemistry and materials sector are mainly those applications where post-manufacturing processing may involve cutting, grinding or spraying of the product. For these, there exists a potential for higher exposure without sufficient occupational hygiene controls in place.

For further information on the hazard of those nanomaterials listed, readers are directed to the ObservatoryNANO baseline studies document⁸ which provides key information on toxicity, ecotoxicity, fate and behaviour, and characterisation considerations for each.

The main routes of potential human exposure to the NPs considered were found to be:

- inhalation of aerosolised or powder NPs during production / manufacture of the matrix in which the NPs are bound
- Inhalation of airborne NPs as a result of cutting or grinding of the matrix-bound materials in their installation etc e.g. for body and trim parts
- following any degradation/abrasion during use
- at disposal or recycling of the product, mainly if this is done in such a manner which may allow release of matrix-bound NP e.g. shredding /crushing

The main routes of potential environmental exposure to the NPs considered were found to be:

- if free particles added within the manufacturing processes are allowed to enter the manufacturing plant waste streams, release into surface/drinking water may occur.
- in disposal or recycling of the product, mainly if this is done in such a manner which may allow release of matrix-bound NP e.g. explosion / combustion

For personnel involved in manufacture of the products, the risk of exposure is generally greater than for any other user group or stage of life cycle, as they are more likely to be coming into contact with free NPs. At this stage, the principal risk of exposure appears to be by inhalation at the current time. For the general public, exposure is more likely to be dependant on abrasion of the product during its use, or via release from the product during or following its demolition/disposal. Environmental exposures may potentially result from any of the stages listed above, particularly if occupational hygiene measures are poor for disposal of waste and by-products.

The following lists detail those applications in which there exists the highest exposure potential.

- **Carbon-based Nanomaterials:** Raised exposure potential to professional users either via air or dermally (depending on method of manipulation/installation). Nanomaterials involved include:

- Carbon black in paints & pigments
- C60 Fullerene in biomedical imaging diagnostics, drug delivery systems and protein markers
- Graphite NPs in pigment production and hydrogen storage
- CNTs in biomedical imaging diagnostics and drug delivery systems
- Carbon films in tribiological applications
- Graphene as a reinforcing filler in composite materials
- Carbon aerogels in thermal insulation or solar energy collectors

Raised exposure to consumers is possible either via air or internally (ingestion/injection) depending on the application involved. Nanoparticles carrying an increased exposure potential include:

- Carbon black in paints & pigments

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- C60 fullerene in biomedical imaging diagnostics, drug delivery systems and protein markers (high exposure likely as used within the human body)
- Graphite NPs in pigment production
- CNTs in biomedical imaging diagnostics and drug delivery systems

Slightly Increased potential for environmental exposure was identified at disposal via crushing, shredding or combustion for:

- Carbon black as a filler material to increase wear-resistance of rubber products, antistatic filler for plastic packaging, in paint and pigment production or as a filler in compound materials
- C60 Fullerene as a friction minimising additive in lubricants, or within solar cells
- Graphite NPs used as an additive in rubber and plastic products, as electrode materials in e.g. batteries, or within hydrogen storage applications
- CNTs used as nanoelectronic transistors, electron emitters in flat panel displays, electrode materials, fillers for anti-static and conductive plastic composites or electrode materials in electrochemical applications
- Nanohorns as electrodes in electrochemical applications
- Graphene as a reinforcing filler in composite materials
- Carbon Aerogels within thermal insulation, or solar energy collectors

Environmental exposure potential was also identified as being slightly increased via entry to wastewater streams or from sewage treatment plants (STP) for:

- C60 Fullerene within drug delivery systems
- Graphite NPs used for pigment production
- CNTs used within biomedical tracers or as drug delivery systems

- **Nanocomposites:** Exposure potential to professional users either via air or dermal contact possible (depending on method of manipulation/installation).

Nanocomposites with raised exposure potential include:

- polymer matrix nanocomposites (POSS) in lightweight construction (dermal)
- Metal ceramic nanocomposites as lubricants in biomedical applications (dermal)
- Quantum Dots (core-shell nanocrystals) in biomedical diagnostics (dermal)

Raised exposure potential for consumers was identified as being possible either via air or internally (ingestion/injection) depending on the application involved. Nanoparticles carrying an increased exposure potential include:

- polymer matrix nanocomposites (POSS) in flame resistant additives
- Metal ceramic nanocomposites in heat and wear resistant coatings for medical implants and as lubricants in biomedical applications
- Quantum Dots (core-shell nanocrystals) in biomedical diagnostics

Slightly increased potential for environmental exposure was identified at disposal via crushing, shredding or combustion for:

- Polymer-nanoclay composites in food applications and packaging, in heat resistant materials and in flame resistant additives
- Metal matrix composites e.g. tungsten carbide NPs embedded in Co matrix used as nano fillers for various applications
- Nanoscale carbon fillers (CNT, fullerene, carbon nanofibres)
- Metal ceramic nanocomposites used within the transport industry

Environmental exposure potential was also identified as being slightly increased via entry to wastewater streams or from sewage treatment plants (STP) for:

- Metal ceramic nanocomposites as lubricants in biomedical applications, and as wear and heat resistant coatings for medical implants
- Quantum Dots (core-shell nanocrystals) used within biomedical diagnostics

- **Nano metals and alloys:** Raised exposure potential to professional users either via air or dermally (depending on method of manipulation/installation). Nanoparticles involved include:

- Titanium in biomedical implants (during handling / implant procedure)
- Noble metals - Au, Ag, Pt, Pd used within biomedical imaging and diagnostics applications and molecular biology (dermal)
- Noble metals (Au) used within biomedical implants & diagnostics, and biomedical imaging (dermal)
- Noble metals - Au, Ag and Pt used within drug development and delivery applications (Dermal)
- Noble metals - (Ag) used within biolabelling and detection (dermal)
- Noble metals - (Ag) used within ink and pigment additives (inhalation or dermal)
- Ferromagnetic NPs used in ICT, medical diagnostics, and as ferrofluids in vehicle braking and suspension systems (dermal)
- Mg-Ni alloys used within hydrogen storage (dermal)
- Metal hydrides used within hydrogen storage (dermal)
- Nanocrystal magnesium furtheron used within hydrogen storage (dermal)
- Nanocrystalline Ti used within medical implants

Raised exposure potential for consumers was identified as being possible either via air or internally (ingestion/injection) depending on the application involved. Nanoparticles carrying an increased exposure potential in include:

- Nanocrystalline Ti used within medical implants
- Noble metals - Au, Ag, Pt, Pd used within biomedical imaging and diagnostics applications
- Noble metals (Au) used within biomedical implants & diagnostics, and biomedical imaging
- Noble metals - Au, Ag and Pt used within drug development and delivery applications
- Noble metals - (Ag) used within biolabelling and detection (dermal), and within ink and pigment additives (inhalation or dermal)
- Al nanopowder used within medical implants
- Ferromagnetic NPs used in medical diagnostics
- Nanocrystalline high grade steel used within biomedical applications
- Nanocrystalline Ti used within medical implants

Environmental exposure potential was identified as being slightly increased via entry to wastewater streams or from sewage treatment plants (STP) for:

- Ti used within biomedical implants
- Noble metals - Au, Ag, Pt, Pd used within biomedical imaging and diagnostics applications
- Noble metals (Au) used within biomedical implants & diagnostics, and biomedical imaging

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- Noble metals - Au, Ag and Pt used within drug development and delivery applications
- Noble metals - (Ag) used within biolabelling and detection
- Ferromagnetic NPs used in medical diagnostics
- Nanocrystalline Ti used within medical implants
- Nanocrystalline high grade steel used within biomedical applications

Environmental exposure potential was also identified as being slightly increased (non-specifically) for:

- Noble metals - (Ag) used within ink and pigment additives
- Mg-Ni Alloys used within hydrogen storage applications
- Metal hydrides used within hydrogen storage applications
- Nanocrystalline magnesium furtheron used within hydrogen storage applications

- **Polymer Nanomaterials:** Raised exposure potential to professional users either via air or dermally (depending on method of manipulation/installation). Nanomaterials involved include:

- Polymer nanostructures in drug delivery systems, medical implants and for tissue engineering
- Nanostructured PMMA-films on the surface of medical implants (via any manipulation at time of fitting)
- polystyrene-polyethylene oxide (PS-PEO) films on biomedical surfaces (via any manipulation at time of fitting)
- Polymer-coatings for biological coatings
- polyacetylbenzene-polydiene nanoparticles (PAB-PDM) in drug delivery systems (via accidental spillage)
- Polymer nanotubes and nanowires for molecular transport, tissue engineering and drug delivery (via accidental spillage)
- Polymer nanofibers in drug delivery systems (via accidental spillage)
- Dendrimers used as base materials for tissue engineering, biomedical coatings or implants (via accidental contact with tissue or manipulation of implant), or in drug delivery systems, protein or enzyme modelling (via accidental spillage)
- Dendrimers used as additives to inks and paints (via inhalation or dermal contact)

Raised exposure potential for consumers was identified as being possible either via air or internally (ingestion/injection) depending on the application involved. Nanoparticles carrying an increased exposure potential in include:

- Polymer nanostructures in drug delivery systems, medical implants and for tissue engineering
- Nanostructured PMMA-films on the surface of medical implants
- Polystyrene-polyethylene oxide (PS-PEO) films on biomedical surfaces (via abrasion or wear and tear)
- Polymer-coatings for biological coatings (via abrasion or wear and tear)
- Polyacetylbenzene-polydiene nanoparticles (PAB-PDM) in drug delivery systems
- Polymer nanotubes and nanowires for molecular transport, tissue engineering and drug delivery
- Polymer nanofibers in drug delivery systems

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- Dendrimers used as base materials for tissue engineering, biomedical coatings or implants, in drug delivery systems or in protein or enzyme modelling

Environmental exposure potential was identified as being slightly increased via entry to wastewater streams or from sewage treatment plants (STP) for:

- Polymer nanostructures used in biomedical implants and tissue engineering
- Nanostructured PMMA-films on the surface of medical implants
- Polystyrene-polyethylene oxide (PS-PEO) films on biomedical surfaces
- Polyacetylene-polydiene nanoparticles (PAB-PDM) in drug delivery systems
- Polymer nanotubes and nanowires for molecular transport, tissue engineering and drug delivery
- Dendrimers used as base materials for tissue engineering, biomedical coatings or implants

Environmental exposure potential was also identified as being slightly increased via crushing, shredding or combustion for:

- Polymer nanostructures used in field emission arrays and OLEDs, and in solar cells as electrode and sensor materials
- Dendrimers used as additives to inks and paints

- **Nanoceramics:** Raised exposure potential to professional users either via air or dermally (depending on method of manipulation/installation). Nanoparticles involved include:

- Titanium oxide nanoparticles in sunscreens and cosmetics (via dermal contact)
- Zinc oxide (ZnO) as a UV filter in sunscreens (via dermal contact)
- Iron oxide nanoparticles in pigments for lacquers and paints (via inhalation or dermal contact)
- Iron oxide nanoparticles used in biomedical research e.g. as contrast agents (via accidental spillage)

Raised exposure potential for consumers was identified as being possible either via air or internally (ingestion/injection) depending on the application involved. Nanoparticles carrying an increased exposure potential include:

- Titanium oxide nanoparticles in sunscreens & cosmetics
- Zinc oxide (ZnO) as a UV filter in sunscreens
- Iron oxide nanoparticles in pigments for lacquers and paints (if released into air during printing)
- Iron oxide nanoparticles used in biomedical research e.g. as contrast agents (via accidental spillage)

Environmental exposure potential was identified as being slightly increased via entry to wastewater streams or from sewage treatment plants (STP) for:

- Titanium oxide nanoparticles in sunscreens and cosmetics (high exposure likely)
- Zinc oxide (ZnO) as a UV filter in sunscreens (high exposure likely)

Environmental exposure potential was also identified as being slightly increased during crushing, shredding or combustion for:

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- Rare-earth oxides (Dy-, Er-, Eu-, Gd-, Nd-, Sm-, Tb-, Yb- and Y-oxides) used in protecting surfaces from degeneration by exposure to UV-radiation
- Iron oxide nanoparticles in pigments for lacquers and paints
- Carbide nano-ceramics (based on e. g. Si, N, B, Ti) used in thermal and mechanical reinforcing or friction lowering coatings
- Nanoparticulate silicon nitride (Si_3N_4) in ball bearings

6. References

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