ObservatoryNANO

Environmental, Health and Safety (EHS) Impacts

Technology Sector Evaluation: Automotive and Aeronautic

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1. Introduction

The automotive and aeronautic industries are key sectors in Europe. The European automotive industry produces 17,1 million passenger cars yearly, 32% of the vehicle manufacturing worldwide[1], and the European Aerospace and defence industry reported a turnover of €132.2 billion in 2007.

The automotive and aeronautics technical sector report[2] provides an overview on processing technologies of nanostructured metals, polymer nanocomposites and tribological coatings for automotive and aeronautics applications.

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

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

- Bulk nanostructured metals
- Polymer nanocomposites
- Tribiological nano-coatings

The key common knowledge gap across all nanoparticle applications is the lack of exposure measurements. 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 to be included in later technical sector EHS analyses should enable 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 that €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, daphids 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) x 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) he 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 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 are similar, those with the highest potential exposure will have the highest potential risks.

Table 1: Potential exposure in applications

Automotive & Aerospace									
				Exposure potential - use (e.g. activity, exposure route, what)				Exposure potential - disposal (e.g. incinerated, landfilled, recycled, STP)	
Sub sector	Application[1)]	Types of NP [2)]	Incorporation in products [3)]	Manufacturer	Professional user	Consumer	Environment	Human	Environment
Section 1.1 - Nanostructured Metals									
1.1	Variety of automotive and aeronautical applications, mainly in structural parts	Aluminium alloys	Smelting process - add NPs as a master batch mixed with something else	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 unless shredded into air or combusted
1.1	Lightweight material in the field of commercial and speciality automotive construction to overcome corrosion	Magnesium	Incorporated into metal	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 unless shredded into air or combusted

Automotive & Aerospace									
				Exposure potential - use (e.g. activity, exposure route, what)				Exposure potential - disposal (e.g. incinerated, landfilled, recycled, STP)	
Sub sector	Application[1)]	Types of NP [2)]	Incorporation in products [3)]	Manufacturer	Professional user	Consumer	Environment	Human	Environment
1.1	Within aircraft in applications where volume is important (e.g. landing gears & attachment points and where the temperature is too high for aluminium, such as near the engine)	Titanium alloys, Titanium with nanograins	Smelting process - add NPs as a master batch mixed with something else.	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 unless shredded into air or combusted
Section 1.2 – Polymer Nanocomposites									
1.2	Timing belt cover with improved mechanical and barrier properties as well as improved thermal resistance	Nylon nano-composites	Incorporation of layered and nanostructured silicate clay into a polyamide 6 polymer matrix to produce a composite material	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
1.2	Engine cover with improved mechanical and barrier properties as well as improved thermal resistance	Nylon nano-composites	Incorporation of layered and nanostructured silicate clay into a polyamide 6 polymer matrix to produce a composite material	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

Automotive & Aerospace									
				Exposure potential - use (e.g. activity, exposure route, what)				Exposure potential - disposal (e.g. incinerated, landfilled, recycled, STP)	
Sub sector	Application[1)]	Types of NP [2)]	Incorporation in products [3)]	Manufacturer	Professional user	Consumer	Environment	Human	Environment
1.2	Barrier fuel line with improved mechanical and barrier properties as well as improved thermal resistance.	Nylon nano-composites	Incorporation of layered and nanostructured silicate clay into a polyamide 6 polymer matrix to produce a composite material	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
1.2	Step assist for GMC Safari and Chevrolet Astro vans	Polyolefin nanocomposites	Incorporation of nanoclay powder to polyolefin resin via high shear processing	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
1.2	Heavy-duty electrical enclosure	Polyolefin nanocomposites	Incorporation of nanoclay powder to polyolefin resin via high shear processing	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

Automotive & Aerospace									
				Exposure potential - use (e.g. activity, exposure route, what)				Exposure potential - disposal (e.g. incinerated, landfilled, recycled, STP)	
Sub sector	Application[1)]	Types of NP [2)]	Incorporation in products [3)]	Manufacturer	Professional user	Consumer	Environment	Human	Environment
1.2	Automotive (various uses)	Forte™ polypropylene -based nanocomposite	Thermoplastic polyolefins and modified polyolefins are compounded with nano-fillers (either tubes (HNT) or clay)	High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding nanocomposite to shape	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
1.2	Thermoset structural composites (Under investigation by GM to replace current composites of this kind)	CNTs		High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding nanocomposite to shape	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
1.2	Interior and exterior automotive applications	Thermoplastic olefin (TPO)		High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding TPO to shape	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

1.2	Dow Automotive (no information on specific use provided)	Nanocomposites based on nanoclay and cyclic buthylene terephthalate (CBT)		High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding nanocomposite to shape	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
1.2	ELAN XP nanocomposite grades for automotive interiors	Polypropylene/ polystyrene blends		High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding nanocomposite to shape	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
1.2	Class A toughened resin system - as replacement for traditional additives to increase the toughness while maintaining all physical properties in	Nanoclays		High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding nanocomposite to shape	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
1.2	Boeing 787 aircraft, multiple applications	Polyketone based nanocomposite - halloysite clay nanotubes	Either injection moulded or extruded, enabling a broad range of applications.	High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding nanocomposite to shape, dermal exposure possible during moulding/extrusion	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
1.2	Automotive fuel systems	Conductive polyoxy-methylene (POM) with Hyperion nanotubes		High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding nanocomposite to shape	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

1.2	Class A body panel and trim parts in automotive industry	MWCNTs in Polyetheretherketone (PEEK)	Thermoplastic masterbatches containing fibril MWCNTs. These nanotubes can be loaded at low rates which allow their use in large exterior panels	High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding body parts to shape	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
1.2	Class A body panel and trim parts in automotive industry	MWCNTs in Polyetherimide (PEI)	Thermoplastic masterbatches containing fibril MWCNTs. These nanotubes can be loaded at low rates which allow their use in large exterior panels	High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding body parts to shape	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
1.2	Class A body panel and trim parts in automotive industry	MWCNTs in Polyphenylene sulphide (PPS)	Thermoplastic masterbatches containing fibril MWCNTs. These nanotubes can be loaded at low rates which allow their use in large exterior panels	High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding body parts to shape	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
1.2	Class A body panel and trim parts in automotive industry	MWCNTs in Polystyrene (PS)	Thermoplastic masterbatches containing fibril MWCNTs. These nanotubes can be loaded at low rates which allow their use in large exterior panels	High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding body parts to shape	low 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
1.2	Class A body panel and trim parts in automotive industry	MWCNTs in Nylon	Thermoplastic masterbatches containing fibril MWCNTs. These nanotubes can be loaded at low rates which allow their use in large exterior panels	High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding body parts to shape	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
1.2	Tubing in the flexible portion of fuel lines	CNT-reinforced nylon 6	Diluting a masterbatch containing a % CNT	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix & will not undergo manipulation by professional fitter	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

1.2	Nanotube filled polyamide/ polyphenylene ether (PA/PPE) blend for sport fenders (renault Clio & Megane)	nanotubes	Diluting a masterbatch containing a % nanotubes	High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding nanocomposite to shape	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
1.2	Moulded fuel tank	Nanoclays	In-situ polymerization to enhance nylon-6 based composites with nanoclays	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix & will not undergo manipulation by professional fitter	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
1.2	Carbon nanotube reinforced polymer composites for mirror housing (Ford Taurus)	CNTs		High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix & will not undergo manipulation by professional fitter	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
1.2	Carbon nanotube reinforced polymer composites for various Body parts	CNTs	Enables composite parts to be painted together with the rest of the auto body and treated in the same process as the metallic body parts	High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding nanocomposite to shape	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
1.2	Carbon fibre composites	CNTs		High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding nanocomposite to shape	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
1.2	CNT based thermoplastics that can be injection moulded	CNTs		High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding thermoplastic to shape, dermal exposure possible	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

					during injection moulding				
1.2	Thermoset nanocomposites	CNTs		High - Release during manufacture is possible, exposure predominantly via air	Medium - inhalation exposure possible if cutting/grinding nanocomposite to shape	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
Section 1.3 – Tribiological Nanocoatings									
1.3	Propulsion systems	Transition metal carbides (e.g. WC or CrC)		High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix & will not undergo manipulation by professional fitter	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
1.3	Hydraulic components	Transition metal carbides (e.g. WC or CrC)		High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix & will not undergo manipulation by professional fitter	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
1.3	Aeronautic wing parts	Transition metal carbides (e.g. WC or CrC)		High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix & will not undergo manipulation by professional fitter	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
1.3	Cermets (composite material composed of ceramic (cer) and metallic (met) materials) to substitute hard chroming galvanised processes, which are toxic	Cermets - CrC-NiCr	Thermally sprayed (by HVOF), coated over steel, aluminium alloys and aluminium matrix composites moulds used in plastic parts production thus contributing to reduce the cycle time	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix & will not undergo manipulation by professional fitter	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

1.3	Cermets (a composite material composed of ceramic (cer) and metallic (met) materials) to substitute hard chroming galvanised processes, which are toxic	Cermets - WC-CoCr	Thermally sprayed (by HVOF), coated over steel, aluminium alloys and aluminium matrix composites moulds used in plastic parts production thus contributing to reduce the cycle time.	High - Release during manufacture is possible, exposure predominantly via air	Low - nanoparticles bound in matrix & will not undergo manipulation by professional fitter	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
1.3	Ceramic coating coated onto metallic substrates such as steel	Al_2O_3	High Velocity Oxygen Fuel - HVOF, Atmospheric Plasma Spraying - APS	High - Release during manufacture is possible, exposure predominantly via air	Exposure potential low, no release during use unless via abrasion	Exposure potential low, no release during use unless via abrasion	Exposure potential low, no release during use unless via abrasion	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding
1.3	Ceramic coating coated onto metallic substrates such as steel	Cr_2O_3	High Velocity Oxygen Fuel - HVOF, Atmospheric Plasma Spraying - APS	High - Release during manufacture is possible, exposure predominantly via air	Exposure potential low, no release during use unless via abrasion	Exposure potential low, no release during use unless via abrasion	Exposure potential low, no release during use unless via abrasion	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding
1.3	Ceramic coating coated onto metallic substrates such as steel	TiO_2	High Velocity Oxygen Fuel - HVOF, Atmospheric Plasma Spraying - APS	High - Release during manufacture is possible, exposure predominantly via air	Exposure potential low, no release during use unless via abrasion	Exposure potential low, no release during use unless via abrasion	Exposure potential low, no release during use unless via abrasion	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding
1.3	Ceramic coating of aluminium alloys	Al_2O_3, Cr_2O_3 and TiO_2	High Velocity Oxygen Fuel - HVOF, Atmospheric Plasma Spraying - APS or High Velocity Suspension Flame Spraying - HVSFS	High - Release during manufacture is possible, exposure predominantly via air	Exposure potential low, no release during use unless via abrasion	Exposure potential low, no release during use unless via abrasion	Exposure potential low, no release during use unless via abrasion	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding
1.3	Ceramic coating of titanium alloys	Al_2O_3, Cr_2O_3 and TiO_2	High Velocity Oxygen Fuel - HVOF, Atmospheric Plasma Spraying - APS or High Velocity Suspension Flame Spraying - HVSFS	High - Release during manufacture is possible, exposure predominantly	Exposure potential low, no release during use unless via abrasion	Exposure potential low, no release during use unless via abrasion	Exposure potential low, no release during use unless via abrasion	Exposure potential very small, no release during use unless via abrasion	Medium - release possible via crushing /shredding

				via air					
1.3	Diesel fuel injection systems	Diamond-like Carbon doped or alloyed by elements such as Si, N	Physical Vapour Deposition; Pulsed laser deposition (PLD) has proved to be an effective technique for low temperature deposition of a wide variety of thin film materials	High - Release during manufacture is possible, exposure predominantly via air	Exposure potential low, no release during use unless via abrasion	Exposure potential low, no release during use unless via abrasion	Exposure potential low, no release during use unless via abrasion	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding
1.3	Gearboxes	Diamond-like Carbon doped or alloyed by elements such as Si, N	Physical Vapour Deposition; Pulsed laser deposition (PLD) has proven to be an effective technique for low temperature deposition of a wide variety of thin film materials	High - Release during manufacture is possible, exposure predominantly via air	Exposure potential low, no release during use unless via abrasion	Exposure potential low, no release during use unless via abrasion	Exposure potential low, no release during use unless via abrasion	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding
1.3	Fuel injection pump components	Diamond-like Carbon doped or alloyed by elements such as Si, N	Physical Vapour Deposition; Pulsed laser deposition (PLD) has proved to be an effective technique for low temperature deposition of a wide variety of thin film materials	High - Release during manufacture is possible, exposure predominantly via air	Exposure potential very small, no release during use unless via abrasion	Exposure potential very small, no release during use unless via abrasion	Exposure potential very small, no release during use unless via abrasion	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding
1.3	Gear and valve train	Diamond-like Carbon doped or alloyed by elements such as Si, N	Physical Vapour Deposition; Pulsed laser deposition (PLD) has proved to be an effective technique for low temperature deposition of a wide variety of thin film materials	High - Release during manufacture is possible, exposure predominantly via air	Exposure potential very small, no release during use unless via abrasion	Exposure potential very small, no release during use unless via abrasion	Exposure potential very small, no release during use unless via abrasion	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding
1.3	Various	Nanocomposite DLC coatings based on crystalline TiC	Physical Vapour Deposition; Pulsed laser deposition (PLD) has proved to be an effective technique for low temperature deposition of a wide variety of thin film materials	High - Release during manufacture is possible, exposure predominantly via air	Exposure potential very small, no release during use unless via abrasion	Exposure potential very small, no release during use unless via abrasion	Exposure potential very small, no release during use unless via abrasion	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding

1.3	Nitrides, carbides and carbon based coatings for aero/auto parts	Nitrides, carbides and carbon - product trade name is BALINIT	Physical vapour deposition (arc-cathodic evaporation and sputtering) and plasma assisted chemical vapour deposition methods.	High - Release during manufacture is possible, exposure predominantly via air	Exposure potential very small, no release during use unless via abrasion	Exposure potential very small, no release during use unless via abrasion	Exposure potential very small, no release during use unless via abrasion	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding
1.3	Specific applications have not yet been found but tribiological coatings constructed this way are on the market	Nanocomposite films made of PECVD	Chemical vapour deposition (CVD)	High - Release during manufacture is possible, exposure predominantly via air	Exposure potential very small, no release during use unless via abrasion	Exposure potential very small, no release during use unless via abrasion	Exposure potential very small, no release during use unless via abrasion	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding
1.3	Nanoscale multilayer (superlattice) coatings to improve the quality of products and reduce lubricant consumption	TiAlYCrN, CrAlYN/CrN, CrN/NbN, TiAlN/VN, TiAlCN/VCN and Me/C	Physical Vapour Deposition nanoscale (superlattice) coatings onto steel used in aluminium cutting tools	High - Release during manufacture is possible, exposure predominantly via air	Low - Exposure potential very small, no release during use unless via wear and tear	Low - Exposure potential very small, no release during use unless via wear and tear	Low - Exposure potential very small, no release during use unless via wear and tear	Low - unlikely humans will come into contact with NPs unless via environmental release	Medium - release possible via crushing /shredding

4.0 Conclusions

The key nanoparticles identified as carrying potential EHS impact across the construction technology sector are outlined in table 2. The two most commonly used types within the sector were CNTs, nylon nanocomposites and metal oxides.

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

	aluminium alloys	Magnesium	titanium alloys, Titanium with nanograins	Nylon nanocomposites	Polyolefin nanocomposites	Forte™ nanocomposite	CNTs	thermoplastic olefin (TPO)	nanocomposites based on nanoclay and cyclic buthylene terephthalate (CBT)	polypropylene/polystyrene blends	nanoclays	polyketone based nanocomposite - halloysite clay nanotubes	conductive polyoxymethylene (POM) with Hyperion nanotubes	nanotubes	transition metal carbides (e.g. WC or CrC)	cermets - CrC-NiCr / WC-CoCr	Al2O3	Cr2O3	TiO2	Diamond-like Carbon doped or alloyed by Elements such as Si, N, F or metals (films labelled "a-C:X").	Nanocomposite DLC coatings based on crystalline TiC	nitrides, carbides and carbon - product trade name is BALINIT	nanocomposite films made of PECVD	TiAlN/VN
Variety (undefined)	•					•			•		•										•		•	
Lightweight materials		•																						
aircrafts landing gears and attachment points			•																					
Timing belt cover				•																				
engine cover				•																				
Barrier fuel line				•																				
Step assist for vans					•																			
heavy-duty electrical enclosure					•																			
to replace current thermoset structural composites						•																		
Interior and exterior automotive applications							•																	
ELAN XP nanocomposite grades for automotive interiors										•														
in place of traditional additives in Class A toughened resin system											•													

	aluminium alloys	Magnesium	titanium alloys, Titanium with nanograins	Nylon nanocomposites	Polyolefin nanocomposites	Forte™ nanocomposite	CNTs	thermoplastic olefin (TPO)	nanocomposites based on nanoclay and cyclic buthylene terephthalate (CBT)	polypropylene/polystyrene blends	nanoclays	polyketone based nanocomposite - halloysite clay nanotubes	conductive polyoxymethylene (POM) with Hyperion nanotubes	nanotubes	transition metal carbides (e.g. WC or CrC)	cermets - CrC-NiCr / WC-CoCr	Al2O3	Cr2O3	TiO2	Diamond-like Carbon doped or alloyed by Elements such as Si, N, F or metals (films labelled "a-C:X").	Nanocomposite DLC coatings based on crystalline TiC	nitrides, carbides and carbon - product trade name is BALINIT	nanocomposite films made of PECVD	TiAlN/VN
Aircraft, broad range of applications.												•												
Automotive fuel systems													•											
Class A body panel and trim parts (car)																								
• Polyetheretherketone (PEEK) based							•																	
• Polyetherimide (PEI) based							•																	
• Polyphenylene sulphide (PPS) based							•																	
• Polystyrene (PS) based							•																	
• Nylon based							•																	
Sport fenders (car)														•										
Tubing in the flexible portion of fuel lines							•																	
moulded fuel tank											•													
mirror housing (car)							•																	
carbon fibre composites							•																	
CNT based thermoplastics							•																	
thermoset nanocomposites							•																	
propulsion systems															•									
hydraulic components															•									
wing parts															•									
chroming galvanised processes																•								
Ceramic coating of steel																	•	•	•					
Ceramic coating of aluminium alloys																	•	•	•					
Ceramic coating of titanium alloys																	•	•	•					

	aluminium alloys	Magnesium	titanium alloys, Titanium with nanograins	Nylon nanocomposites	Polyolefin nanocomposites	Forte™ nanocomposite	CNTs	thermoplastic olefin (TPO)	nanocomposites based on nanoclay and cyclic buthylene terephthalate (CBT)	polypropylene/polystyrene blends	nanoclays	polyketone based nanocomposite - halloysite clay nanotubes	conductive polyoxymethylene (POM) with Hyperion nanotubes	nanotubes	transition metal carbides (e.g. WC or CrC)	cermets - CrC-NiCr / WC-CoCr	Al2O3	Cr2O3	TiO2	Diamond-like Carbon doped or alloyed by Elements such as Si, N, F or metals (films labelled "a-C:X").	Nanocomposite DLC coatings based on crystalline TiC	nitrides, carbides and carbon - product trade name is BALINIT	nanocomposite films made of PECVD	TiAlN/VN
Diesel fuel injection systems																				•				
Gearboxes & fuel injection pump components																				•				
Gear and valve train																				•				
Coatings for aero/auto parts																							•	
Tubing in the flexible portion of fuel lines				•																				
Quality improvements on tools & products																								•

Applications in which potential EHS issues were identified for nanomaterials used within the automotive and aeronautic 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 document[8] 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 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. 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 come into contact with free NPs. At the current time, the principal risk of exposure appears to be by inhalation. 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 list details those applications in which there exists the highest exposure potential. These are interior and exterior body and trim parts which require cutting/grinding into shape and thus present a risk of inhalation exposure, or which may be sprayed or injected and thus present a potential for dermal exposure to professional users. In addition, fuel tanks and associated systems may undergo shredding /crushing at disposal and lead to release into the environment.

- **Interior and exterior automotive and aeronautic body parts:** Raised exposure potential to professional users either via air or dermally is possible (depending on method of manipulation/installation). Exposure at disposal is raised if process of demolition likely to result in NPs being freed e.g. via crushing / shredding. These include:
    - Forte™ polypropylene-based nanocomposite
    - CNTs
    - thermoplastic olefin (TPO)
    - nanocomposites based on nanoclay and cyclic buthylene terephthalate (CBT)
    - polypropylene/polystyrene blends
    - nanoclays
    - polyketone based nanocomposite - halloysite clay nanotubes
    - carbon nanotube reinforced polymer composites and thermoplastics

- **Class A body panel and trim parts in the automotive industry:** Raised exposure potential to professional users either via air or dermally is possible (depending on method of manipulation/installation). Exposure at disposal is raised if process of demolition likely to result in NPs being freed e.g. via crushing / shredding. These include:
  - MWCNT reinforced polyetheretherketone (PEEK) body/trim parts
  - MWCNT reinforced polyetherimide (PEI) body/trim parts
  - MWCNT reinforced polyphenylene sulphide (PPS) body/trim parts
  - MWCNT reinforced polystyrene (PS) body/trim parts
  - MWCNT reinforced nylon body/trim parts
- **Fuel tanks and associated systems:** Raised exposure potential at disposal if process of demolition likely to result in NPs being freed e.g. via crushing / shredding. These include:
  - nanoclay-based moulded fuel systems
  - fuel systems constructed using conductive polyoxymethylene (POM) with Hyperion nanotubes
  - tubing in the flexible portion of fuel lines using CNT-reinforced nylon-6

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