DWI 70/2/246

REVIEW OF THE RISKS POSED TO DRINKING WATER BY MAN-MADE NANOPARTICLES

This document is a final report by the Food and Environment Research Agency (Fera) for the Drinking Water Inspectorate (DWI).

The authors gratefully acknowledge funding from the Department for Environment, Food and Rural Affairs (Defra). The views and interpretation expressed in this report are those of the authors, and do not necessarily represent views of the Department or DWI.

K Tiede, P Westerhoff, S Foss Hansen,

GJ Fern, SM Hankin, RJ Aitken, Q Chaudhry, and ABA Boxall

Food and Environment Research Agency
Sand Hutton
York
YO41 1LZ

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Executive Summary

There is increasing concern over the health effects of engineered nanoparticles (ENPs). Humans can be exposed to these particles directly during product use or indirectly following release to the natural environment. One potential indirect exposure route is through the consumption of contaminated drinking waters. This study therefore explored the potential for ENPs to contaminate drinking water supplies and to establish the significance of the drinking water exposure route compared to other routes of exposure. This study examined risk in the sense of likelihood of exposure to nanoparticles via drinking water, analysis of health risks was beyond its scope.

The study began with a detailed review of the occurrence and quantities of engineered nanoparticles in different product types as well as possible release scenarios (direct & indirect release to air, soil and water), their possible fate and behaviour in raw water and during drinking water treatment. Based on the available data, engineered nanoparticles which are likely to reach water sources (such as ENPs that are produced in large quantities or are used in a free form) were identified and categorised. The classification was based on a categorisation framework to aid exposure assessment of nanomaterials in consumer products.

A conservative approach was used to estimate worst case concentrations of engineered nanoparticles in raw water and treated drinking water, using a simple exposure model.

Exposure estimates for raw water and treated drinking water were then qualitatively compared to available estimates for human exposure through other routes, e.g. direct exposure from consumer products. This allowed an estimate of the amount of exposure to a range of engineered nanoparticles from drinking water as well as a relative qualitative risk of exposure to ENPs from drinking water compared to other routes.

A range of metal, metal oxide and organic-based ENPs were identified that have the potential to contaminate drinking waters. Worst case predicted concentrations in drinking waters were in the low to sub- μg/l range and more realistic estimates were tens of ng/l or less. For the majority of product types, human exposure via drinking water is predicted to be less important than exposure via other routes. The exceptions were some clothing materials, paints and coatings and cleaning products.

The particles contained in these products include Ag, Al, TiO_2, Fe_2O_3 and carbon-based materials. Although predicted concentrations of these materials in UK drinking water are low, any future work on risks of ENPs to drinking waters should probably focus on these materials and the development of the UK market for products containing these materials.

It is clear from this study that there are significant gaps in our current knowledge regarding the use, environmental fate and exposure of ENPs in the UK environment, and recommendations for future studies are made in this report. It should also be noted that this is a product by product analysis and does not reflect human exposure at an individual level.

1. Introduction

The advent of nanotechnology offers enormous prospects for the development of new products and applications in the industrial and consumer sectors. While the majority of manufacturing and use of nano-scale materials occurs in the United States, the European Union, with its 30% global share of the sector, is not lagging far behind in this field (Chaudhry et al. 2005, Aitken et al. 2006). The current and projected applications of engineered nanoparticles (ENPs) worldwide span a wide range of sectors, including catalysts, lubricants and fuel additives; paints and coatings; cosmetics and personal care products; medical, dental, drug delivery and bionanotechnology; functional coatings; hydrogen storage and fuel cells; nanoelectronics and sensor devices; optics and optic devices; security and authentication applications; structural (composite) materials, conductive inks and printing; UV-absorbers and free-radical scavengers; construction materials; detergents; food processing and packaging; paper manufacturing; agrochemicals, plant protection products, and veterinary medicines; plastics, and weapons and explosives (Chaudhry et al. 2005, Aitken et al. 2006). ENPs can also be used for water treatment and remediation of contaminated environments (e.g. nano-Fe).

The rapid proliferation of nanotechnology in the consumer product sector has raised a number of technological, health and safety, environmental, ethical, policy and regulatory issues. These concerns have been most clearly expressed in the 2004 review carried out by the Royal Society and Royal Academy of Engineering (Royal Society and Royal Academy of Engineering 2004), and a number of recent articles (Maynard et al. 2006, Chaudhry et al. 2006, Chaudhry et al. 2007, Boxall et al. 2007).

In many applications, ENPs are present either in a bound, fixed or embedded form, and hence may not pose a risk to the consumer's health or to the environment (if used and disposed of properly). Some applications on the other hand are not bound, fixed or embedded and therefore have a high likelihood of human or environmental exposure. Some of these products may give rise to direct human exposure to free ENPs via inhalation (e.g. cleaning aids, spray cosmetics, coatings), dermal penetration (e.g. cosmetics), ingestion (food and drinks), or intravenous routes (e.g. some medicines and diagnostic aids). The estimation of exposure in such cases is not difficult. It is also possible that ENPs will be released to the natural environment and will enter drinking waters or the food chain. Such exposure may arise from emissions during manufacture, use, and/or disposal of ENP-containing products. Some applications may involve a deliberate release of ENPs in the environment (e.g. for water treatment, ship or exterior paint, environmental remediation). Assessment of the extent of exposure arising from these indirect routes is a major challenge and research into the exposure of humans to ENPs in the environment is lacking. This is partly due to the fact that robust and sensitive analytical methods are not yet available for detecting and characterising ENPs in complex environmental matrices such as soils and natural waters (e.g. Tiede et al., 2009). In addition, the many application of ENPs are very new or yet to be realised so current releases of some ENPs is very low/non-existent at the current time.

One approach to establishing the risks of ENPs arising from indirect exposure is to use exposure modelling which uses information on the amounts of particles in use/expected to be in use, product usage patterns and environmental characteristics to estimate levels in different matrices. Such exposure model predictions can aid the design of toxicological and fate research and provide data for use during nanoparticle risk assessment and subsequent regulatory decision-making.

The aim of this study was therefore to investigate the potential contamination of drinking water supplies by man-made nanoparticles. As a first step, those ENP containing products on the UK market were identified that are likely to result in ENP release to source waters. ENP concentrations in raw and treated drinking waters were then estimated using simple exposure models. The exposure estimates were then compared with assessments of human exposure via other routes to determine whether drinking water is a significant exposure route for different ENPs or not.

The results of the study will benefit numerous stakeholders including Defra, DWI, water companies, the Environment Agency and various users of water concerned with possible contamination by man-made nanomaterials. The provided information will allow stakeholders to understand the potential for ENPs to reach drinking water and the relative exposure compared to other routes.

2. Objectives

The overall aim of this study was to investigate the potential risks, posed to drinking water, by man-made nanoparticles. This was achieved using the following specific objectives:

1. To identify the types of existing products, containing man-made nanoparticles, that are currently used in the UK and also to report on possible trends in use (including new uses) and identify quantities used (Chapter 3)

2. To identify those uses that are likely to result in man-made nanoparticles reaching water sources (Chapter 4)

3. To estimate concentrations of nanomaterials in raw waters based on knowledge of inputs, removal during transmission to water, dilution within the water body and fate and removal within the environment (Chapter 5)

4. To estimate likely concentrations in drinking water based on knowledge of particle removal in treatment (Chapter 5)

5. To compare estimates for exposure from treated drinking water with other estimates/measurements for human exposure through other routes (Chapter 6)

6. To identify major knowledge gaps and develop suggestions on how to fill these (Chapter 7)

3. Products containing man-made nanoparticles currently used in the UK and future usage trends

A variety of consumer products that contain ENPs are already available in the UK/EU. Examples of these include metallic ENPs in nano-coatings on self-cleaning surfaces, medical devices, paints and coatings, fuel catalysts, food packaging and cosmetics. A number of food supplements are also available that contain organic ENPs. The current market indicators suggest that many more consumer products containing ENPs are likely to become available in the coming years, potentially impacting every walk of life (Chaudhry et al., 2008; Boxall et al., 2007; Aitken et al., 2006).

Fera has developed the first UK nanomaterials database for Defra project CB 1070 "Scoping study on the manufacture and use of nanoparticles and nanotubes in the UK" (Chaudhry et al., 2008; Boxall et al., 2007; Aitken et al., 2006). In this Chapter we have built upon this previous work to develop an up-to-date data set on current and future usage of nanomaterial containing products in the UK. A literature search was performed and data were collated from a wide range of information sources including scientific peer-reviewed and grey literature as well as product patents, existing inventories and databases (e.g. Nanotech Inventory of the Woodrow Wilson International Institute for Scholars) and published reports.

Where available, collated data included information on:

- the types of ENP-containing materials, products and applications that are currently available in the UK;
- those materials and applications that are not currently available in the UK but may become available in the short term;
- production volumes and man-made nanoparticle concentrations in products;
- the nature of the ENP in a product (e.g. size, functionality, composition);
- how the ENPs are used/applied in the product (location in the product, matrix); and
- current manufacturing and usage patterns and market trends in relation to new developments that may currently be at the R&D stage, but may become available in the near future.

3.1 Background

There are a number of definitions that are aimed at capturing the nano-specific features of engineered nanomaterials (ENMs). The most notable are those proposed by RS/RAE (Royal Society and the Royal Academy of Engineering, 2004), BSI (British Standards Institution, accessed Dec 2009), ISO (International Organization for Standardization, 2008), Organisation for Economic Co-operation and Development (OECD, 2007), SCENIHR (the EC's Scientific Committee on Emerging and Newly Identified Health Risks, 2007), and EFSA (European Food Safety Authority, 2009). Essentially, an ENM is a material, which is intentionally produced in the nanoscale (approximately 1 nm to 100 nm) to have specific properties or composition. An ENM may contain discrete nanostructures, such as a nanosheet, nanorod (nanofibre, nanowire, nanowhisker), nanotube, or nanoparticles. The main nano-specific features of ENMs derive from their size, shape, specific surface area and surface chemistry. Their behaviour and fate in the environment is further determined by a variety of factors – such as degree of agglomeration or aggregation, solubility and interactions with other materials in the environment (e.g. binding, chemical reactions, degradation etc).

The chemical substance(s) that constitute an ENM can be classified into the following main categories:

- inorganic nanomaterials – these include metals (titanium, zinc, silver, calcium and magnesium), metal oxides and metal nitrides and non-metals such as selenium and silicates.
- organic nanomaterials – these include nanopolymers and nanomedicines as well as nano-carrier systems (e.g. encapsulates) containing antimicrobials, and nutritional and health supplements etc.
- surface functionalised nanomaterials – these may be inorganic materials that are surface functionalised with organic moieties, or vice versa. Examples include organically modified nanoclays for food packaging applications.

In relation to the potential contamination of drinking water with ENMs, it is important to consider the likely sources and environmental loadings of different materials that may end up in the environment at any stage in the lifecycle of a material or product (i.e. production, formulation, packaging, distribution, use, recycling or disposal). In this respect, it is important to consider:

- the nature of ENMs that are (or likely to be) produced in large enough quantities to give rise to a significant environmental loading
- the nature of use(s) of a material or product
- the nature of end-of-life treatment (disposal, recycling, reuse)
- the behaviour and fate of ENM in different environmental conditions

In view of these, a review of existing and projected application of ENMs in a wide range of sectors has been carried out and the results are presented below.

It should be noted that the report aims to assess the risks posed to drinking water by man-made or engineered nanoparticles (ENPs), a subcategory of ENMs. ENPs are mainly referred to as nanospheres with 3 dimensions below 100 nm (Tiede et al. 2008). Initially all products on the UK market containing ENMs were considered as they are potential sources of ENPs released into the environment.

3.2 Summary of findings

The current and projected applications of ENMs span a wide range of sectors. These include fuel catalysts; paints and coatings; cosmetics and personal care products; medical and dental, drug delivery, bionanotechnology; hydrogen storage and fuel cells; nanoelectronics and sensor devices; security and authentication applications; structural (composite) materials, conductive inks; UV-absorbers and free-radical scavengers; detergents; food processing and packaging; paper manufacturing; agrochemicals, human and veterinary medicines, weapons and explosives etc. (Chaudhry et al. 2005; Aitken et al. 2006). Other uses of ENMs are also being considered that involve deliberate release of ENMs in the environment, such as the use of nano-formulated agrochemicals in food production (currently at R&D stage), and the use of ENMs in water treatment (already in use in some countries).

3.3 Scales of ENM production/ use

A number of reports have estimated the level of commercial scale production and use of ENMs. For example, the RS/ RAE review (Royal Society and Royal Academy of Engineering, 2004) estimated the production of ENMs for:

- structural applications (ceramics, catalysts, composites, coatings, thin films, powders, metals) at 10 tonnes in 2003-04, predicted to increase to 1000 tonnes by 2010 and between 10,000 and 100,000 tonnes per year by 2020;
- skin-care applications (mainly metal oxides – such as titanium dioxide, zinc oxide and iron oxide) to stay approximately at a similar level of around 1000 tonnes per year between 2003-04 and 2020;
- information and communication technologies (carbon nanotubes, titanium dioxide, zinc oxide, iron oxide and organic light-emitting diodes) and for instruments and sensors at 10 tonnes in 2003-04, predicted to increase to 100 tonnes by 2010 and 1000 tonnes or more by 2020;
- biotechnology applications (nanoencapsulates, ENMs for targeted drug delivery, bio-compatible ENMs, quantum dots, composites, biosensors etc) at less than 1 tonne in 2003-04, predicted to increase to 1 tonne in 2010 and 10 tonnes per year in 2020;
- environmental applications (such as nanofiltration ad membranes) at around 10 tonnes in 2003-04, predicted to increase to 100 tonnes in 2010 and between 1000 and 10,000 tonnes in 2010.

Other reports, such as by Aitkin et al. (2008), have identified ENMs that are produced in high production volumes. These include silver, carbon black, amorphous silica, titanium dioxide, zinc oxide, nanoclays, carbon materials (fullerenes and carbon nanotubes), cerium oxide, iron, organic materials and other commercially produced ENMs (Table 3.1).

Table 3.1: ENMS produced at industrial high-tonnage scales

ENM	Main Application Areas
Silver	Nano-silver is currently the most commonly used ENM in a wide range of consumer products. An increasing number of nano-silver containing products is available, including cosmetics and personal care products, food and health-food, antimicrobial paints and coatings, hygienic surfaces and packaging materials, and medical applications etc. Indeed, the number of products incorporating nano-silver as an antimicrobial, antiodorant and a (proclaimed) health supplement has surpassed all other ENMs currently in use in different consumer sectors.
Carbon black	Carbon black is a produced at industrial scales in high tonnage volumes, and has applications in tyre manufacturing.
Fumed (amorphous) silica	Fumed amorphous silica is produced in high tonnage volumes, and used for a variety of applications. These include paints and coatings, polishing microelectronic devices, food contact surfaces and food packaging applications. Advantages of nanosilica based paints and coatings include a reduction in the amount of materials and solvents, extended life of paints and coatings that reduces the frequency of re-coating. For example, scratch resistance of coatings can also be improved dramatically by adding ~15% of nano-silica. Porous silica is used in nano-filtration of water and beverages. Amorphous silica is also believed to be used food applications, such as in clearing of beers and wines, and as a free flowing agent in powdered soups.
Titanium dioxide	Nano-titanium dioxide is produced in high tonnage volumes for main uses in paints and coatings (as a UV absorber to help prevent UV degradation), cosmetics (in sunscreens to prevent UV damage to skin), and packaging applications. The use of nano-titanium dioxide may also extend to foodstuffs in the future.
Zinc oxide	Zinc oxide is currently produced in small but growing tonnage volumes. It is mainly used in cosmetics and personal care products, but other applications such as antimicrobial packaging, have also emerged recently.
Nanoclays	Nanoclays are used for a variety of applications. The nanoclay mineral most commonly used is montmorillonite (also termed as bentonite), which is a natural clay obtained from volcanic ash/rocks. Nanoclays have a natural nano-scaled layer structure and are often organically modified to bind to polymer matrices to develop improved materials, such as composites with enhanced gas-barrier properties for food packaging.

ENM	Main Application Areas
Fullerenes and carbon nanotubes	Carbon nanotubes (CNT) are elongated tubular structures, typically 1-2 nm in diameter and can be more than 1 mm in length. CNTs can also be formed as single-wall carbon nanotubes (SWCNTs), or multi-wall carbon nanotubes (MWCNTs). CNTs have very high tensile strength, and are considered to be stronger than steel, whilst being only one sixth of its weight, making them potentially the strongest, smallest fibre known. They also exhibit high conductivity, high surface area, distinct electronic properties, and potentially high molecular adsorption capacity. Because of the high tensile strength, the main of use of CNTs is in structural materials, such as ceramic and polymer composites, conducting composites for the aerospace, automotive and electronics industries, and in adhesives such as epoxy resin. A major area of CNT application is in the electronics sector. Because of the greater mechanical strength and heat-dissipation, CNTs are likely to be used in heat-transfer units in a variety of electronic devices, such a computers, display devices etc. Other uses vary from still under R&D (such as capacitors, flexible displays, hydrogen storage devices, solar (photovoltaic) cells, (bio)sensors) to near market (such as flat panel displays). Another major area of potential large-scale application of CNTs is as a cathode material in lithium-ion secondary (rechargeable) batteries. A number of published studies have indicated the potential of CNTs for use in batteries as a superior material for storage of charge (Kohler et al. 2008). This application area is probably not widespread at present, but is likely to open up a wide range of applications such as in batteries for laptop and mobile phones in the near future. Other potential applications include textiles in which CNTs are spun, coated on surface, or dispersed in the polymer matrix. Because of the high cost of CNTs, these areas of application have so far not seen a widespread use of CNTs, but future low-cost manufacturing may lead to large-scale applications in this area. There are further applications of CNTs that are currently at R&D stage. These include sensing devices (e.g. chemical and pressure sensors, biosensors), biomedical applications (CNT based drug delivery vehicles), energy storage, industrial adhesives and other composite materials (such as for stronger packaging). CNTs are already produced in multi-tonne volumes, and the production is likely to increase in the future. The large-scale production of CNTs has already brought the price of CNTs from ~\$200/ gram in 1999 to around \$50 per gram.
Cerium oxide	Nano-sized cerium oxide is used as a secondary fuel catalyst in diesel. The application is claimed to reduce fuel consumption and particulate emissions. Typically added to diesel at a concentration of 5-10 ppm, nano-cerium oxide is claimed to increase fuel efficiency by ~10%. The catalyst is already in use on a large scale in bus fleets in a number of countries including the UK, Philippines and New Zealand.

ENM	Main Application Areas
Iron	Zero-valent nano-iron is finding an increasing use in water treatment and for the remediation of contaminated soils. Nano-iron is used in the treatment of contaminated waters, e.g. groundwater, where it is claimed to decontaminate water by breaking down organic pollutants and killing microbial pathogens.
Organic ENMs	A wide range of organic ENMs is available, or under R&D, for uses mainly in cosmetics, food and medicine sectors. Examples of the available ENMs include vitamins, antioxidants, colours, flavours, preservatives, active ingredients for cosmetics and therapeutics, detergents etc. The main tenet behind the development of nano-sized organic substances is the greater uptake, absorption and bioavailability of bioactive substances in the body, compared to conventional bulk equivalents. This category of ENMs also includes nano-carrier based delivery systems for drugs, cosmetics, nutrients and supplements. These are based on nanoencapsulation of the substances in liposomes, micelles, or other biopolymers. Whilst the concept of nano-carrier systems has originated from targeted drug delivery, they are finding increasing applications in the cosmetics and food sectors.
Other ENMs	Other ENMs that are produced at an increasing commercial scale include metal and metal oxides of aluminium, copper, tin, zirconium, metal nitrides (e.g. titanium nitride), alkaline earth metals (calcium, magnesium), non-metals (selenium). Quantum dots – composed of metal(oxide), or semiconductor materials with novel electronic, optical, magnetic and catalytic properties are also finding increasing applications in medical imaging and diagnostics and security printing. Due to high cost, the production of quantum dots is not in high-tonnage at present.

A major determinant in the large scale production and use of ENMs is the cost of materials. More expensive ENMs are likely to be used only in small quantities, or for niche applications. The following estimates of the costs of ENMs have been compiled by Wijnhoven et al. (2009):

- more than $50,000 per kg - quantum dots (including nanophosphors), rhodium
- $5,000 to $50,000 per kg - Platinum, silver, palladium, hydroxyapatite
- $50 to $500 per kg - iron oxide, alumina, lithium, carbon nanotubes and composites containing carbon nanotubes, chromium, cobalt, carbon, silica, zirconium, silicon carbide, polyurethane/alumina nanocomposites

- $5 to $50 per kg - alumina, polymer, titanium dioxide, zinc oxide, nanoclay, silica hydride, silica aerogel

3.4 Use of engineered nanomaterials that have the potential to contaminate drinking water

A recent report by Wijnhoven et al., (2009) provides a comprehensive analysis of the current and projected scales of the use of ENMs in consumer products. The report derives data from a number of databases and inventories, such as the Woodrow Wilson database (Woodrow Wilson Nanotechnology Consumer Product Inventory, accessed Dec 2009) containing around 803 products in 2008, Nanotech Product Directory (Nanoshop, accessed Dec 2009) containing 433 products and services, BCC Research (2008), and Nanoposts (accessed Dec 2009).

Table 3.2: The scales of ENMs (tonnes) used in consumer products on the global market (Wijnhoven et al. 2009); categories that have a high potential (based on estimated production volumes; column 1) to be released to the environment and contaminate drinking water supplies are highlighted in grey.

Category (current global production scale)	**ENMs**	**Comments**
Paints, coatings and adhesives (>10,000 tonne)	Currently the largest category of potential ENM use. The main ENMs used are titanium dioxide, zinc oxide, silica (including organo-silica), alumina, and currently low but increasing use of silver in biocidal coatings.	In most cases ENMs will be fixed in the paint/coating matrix. However, environmental degradation may release ENMs into water (Kaegi et al. 2008). Overall environmental loadings of ENMs from this category may be high because of the large volumes of ENMs produced/used.

Category (current global production scale)	**ENMs**	**Comments**
Food Packaging (>10,000 tonne)	Large category of potential ENM use. The ENMs used include nanoclay, silver, titanium nitride, alumina, and silica.	Apart from surface coatings, in most cases the ENMs will be bound or embedded in polymer matrix. The release of ENMs into the environment is expected to be low. However, this will be dependent on how end-of-life treatments for the packaging material are carried out – i.e. whether recycled, incinerated or landfilled.
Catalytic converters for motor vehicles (>10,000 tonne)	Large category of potential ENM use. The ENMs used include alumina, and platinum and palladium (the latter two currently in low tonnage due to high cost).	The entry of the ENMs into the environment is expected to be low due to bound nature of ENMs, but will be dependent on the nature of end-of-life treatments.
Motor vehicle interior (1,000-10,000 tonne)	Medium category of ENM use. The ENMs used include nanoclay, polymer, carbon.	ENMs will be bound or embedded in polymer matrix. The release of ENMs into the environment is expected to be low, but will be dependent on the nature of end-of-life treatments
Cosmetics (mainly UV absorbers) and personal care products (1,000-10,000 tonne)	Medium category of ENM use. The main ENMs used include titanium dioxide and zinc oxide, and currently a small scale use of silver, hydroxyapatite, and fullerenes.	This category is most relevant to potential for contamination of aquatic environments due to direct release of ENMs into wastewaters during use and on disposal.
Insulation material (1,000-10,000 tonne)	Medium category of ENM use. The main ENMs used include silica aerogel.	ENMs will be bound or embedded in polymer matrix. The release of ENMs into the environment is expected to be low. However, this will also be dependent on the nature of end-of-life treatments.

Category (current global production scale)	**ENMs**	**Comments**
Hard disk media (1,000-10,000 tonne)	Medium category of ENM use. The main ENMs used include chromium, cobalt and carbon.	The release of ENMs into the environment is expected to be low. However, this will also be dependent on the nature of end-of-life treatments.
Photocatalytic coatings (1,000-10,000 tonne)	Medium category of ENM use. The main ENMs used include TiO_2.	The release of ENMs into the environment is expected to be low. However, this will also be dependent on the nature of end-of-life treatments.
Magnetic recording media (1,000-10,000 tonne)	Medium category of ENM use. The main ENMs used include iron oxide.	The release of ENMs into the environment is expected to be low. However, this will also be dependent on the nature of end-of-life treatments.
Cladding of optical fibres (1,000-10,000 tonne)	Medium category of ENM use. The main ENMs used include silica based nanofilm.	The release of ENMs into the environment is expected to be low. However, ENM release will be dependent on the lifecycle of the fibres.
Wire and cable sheathing (100-1000 tonne)	Small category of ENM use. The main ENMs used include nanoclay.	The release of ENMs into the environment is expected to be low. However, ENM release will be dependent on the lifecycle of the cables.
Flat panel display (100-1000 tonne)	Small category of ENM use. The main ENMs used include display polymer.	The release of ENMs into the environment is expected to be low. However, ENM release will be dependent on the end-of-life treatments of the displays.
Anti-scratch/stick cleaning products (100-1000 tonne)	Small category of ENM use. The main ENMs used include polyurethane/alumina nanocomposites. Other ENMs used at a smaller scale include alumina, silica, titanium, zirconium and silicon carbide.	Potential for release into water will be high.

Category (current global production scale)	**ENMs**	**Comments**
Eyeglass/lens coating (100-1000 tonne)	Small scale use of ENMs. The main ENMs used include nano polymer thin film coating.	Potential for release into water during use due to natural wear and tear.
Water filtration/ treatment systems (10-100 tonne)	Small scale use of ENMs. The main ENMs used for water filtration include alumina and porous silica. Titanium dioxide and zero-valent iron are also used for treatment of wastewaters.	Potential for release into water is high. The solubility of ENMs or their transformation products will also determine whether insoluble ENMs can be present in aqueous environments.
Fuel additives (unknown but likely to be in multi-tonne scales).	Small category of ENM use. The main ENMs used include cerium oxide (CeO)	Direct release into the environment (air), and expected to end up in aquatic environment.
Sporting goods/equipment (10-100 tonne)	Small category of ENM use. The main ENMs used include composites (inc CNT).	ENMs will be bound or embedded in polymer matrix. The release of ENMs into the environment is expected to be low. However, ENM release will also be dependent on the end-of-life treatments of the products.

Category (current global production scale)	ENMs	Comments
Other small or R&D scale use categories	- optical recording media (alumina thin film) - xenon lighting (alumina) - catalytic converters (rhodium) - ferrofluids for electronics use (iron oxide) - fabric treatment (coating polymers containing ENMs) - antimicrobial dressings (silver) - air purification systems (titanium dioxide) - lithium ion batteries (lithium) - light emitting diodes (lighting quantum dots) - Agrochemicals SiO_2 (porous) as carrier - Pharmaceuticals and medicines - Nanomedicines and carriers	Likely entry of ENMs into the environment is expected to be low, mainly because of the small-scale uses at present, and/or the fixed nature of ENMs in other materials. However, with a decrease in ENM cost some applications may require large scale uses in the future. One such example is the use of CNTs in rechargeable batteries and fabric coatings, which are likely to increase in the future. As with other products, the expected levels of ENMs in water will also be dependent on the end-of-life treatments. For example, whether CNT-containing batteries are collected separately and recycled or subjected to incineration, or are disposed of through landfilling.
Algae preventers for fish tanks, patios and possibly swimming pools (Unknown production scale)	The main ENMs used include lanthanum.	Direct release of the ENM into the aquatic environment.

In relation to potential contamination of the aquatic environment, it is important to consider the whole lifecycle of ENMs and ENM-containing products. So far, there have been only a handful of studies published in this area. A life-cycle study by Mueller and Nowack (2008) modelled the quantities of three ENMs (Ag, TiO_2 and CNT) released into the environment. The results of the study identified TiO_2 as one of the ENMs worth further investigations. Another study by Boxall et al. (2007) estimated the concentrations of ENMs in water, air and soil through modelling. For the 10% market penetration model (which probably slightly overestimates current use volumes), concentrations of Ag, Al_2O_3 and fullerene were predicted to be in ng/l levels in rivers receiving wastewater effluents, whereas TiO_2, silica, ZnO and hydroxyapatite were predicted to be in µg/L range. These estimates were, however, based on simple modelling parameters and did not take into account the potential accumulation of ENPs in the environment over time.

3.5 Application areas most relevant for drinking water - conclusions

From the available information on the scales of production/use, cost of materials, and the likely release patterns into the environment, the following application areas have been regarded the most relevant in relation to potential for contamination of drinking water sources:

- Paints, coatings, and adhesives: Although in most cases ENP will be fixed in, or bound to, the paint/coating matrix. However, environmental degradation over time may release ENPs into the aquatic environment. Overall environmental loading from this area of application may be high because of the shear high volumes of ENMs produced/used in these categories. The ENMs to consider include titanium dioxide, zinc oxide, silica (including organo-silica), alumina, and silver.
- Cosmetics and personal care products: This category is the most relevant in terms of potential for contamination of aquatic environments due to direct release of ENMs into waters both during use and on disposal of the products. The main ENMs to consider include titanium dioxide and zinc oxide, silver, hydroxyapatite, and fullerenes.
- Cleaning products: This small-scale use category is relevant in terms of potential for contamination of aquatic environments due to direct release of ENMs into wastewaters during use and on disposal of the products. The main ENMs to consider include alumina and alumina- polyurethane nanocomposites, silica, titanium, zirconium and silicon carbide.
- Eyeglass/lens coating: This is a small scale use category, but the ENMs used may enter the aquatic environment. The main ENM to consider include nano polymer thin film coating.

- Water treatment/ filtration system: Currently a small use category, but likely to increase in the future (growing use in developing countries). The ENMs used in this category may end up in water (dependent on solubility and stability of the materials in water). The main ENMs used include alumina, zero-valent iron, and titanium dioxide.
- Fuel additives: This small scale use category is important because it will lead to direct release of ENMs into the air, expected to end up in the aquatic environment. The main ENMs to consider is cerium oxide (CeO)
- Algae preventers: This product category will lead to direct release of ENMs into the aquatic environment. The main ENM to consider is lanthanum. The current production/use scales are unknown.

From the available information on current and short-term projected uses presented above, the following ENMs have been identified as the most important in terms of potential for contaminating drinking water sources:

- Titanium dioxide
- Silica
- Alumina
- Zinc oxide
- Silver
- Hydroxyapatite
- Cerium oxide
- Lanthanum
- Iron (and iron oxides)

There are a few other areas that are relevant to contamination of drinking water sources, but are currently under R&D or are near market. These areas will need monitoring for future developments and include:

- The use of carbon nanotube based catalyst coatings in water treatment
- The use of ENMs (not clear which ENMs, although one report suggests fullerenes (In pipeline, accessed Dec 2009)) in coatings inside drinking water pipes

- The use of ENMs in nanomedicines (a variety of human and veterinary medicine applications are being proposed) and medical diagnostics (silver, Fe, magnetic ENMs)
- The use of ENMs as agrochemicals

Other ENMs mentioned in this report seem to have a comparatively lesser potential for contaminating drinking water sources. However, the likelihood of this may change due to, for example, an increase in their scales of production and use in the future (e.g. due to a decrease in material costs, or a new application), or if certain uses or disposal options are found to release ENMs into the environment in significant amounts.

The use of nano-silver in a number of applications, for example, is on the increase worldwide, and is raising concerns over potential environmental impacts in the future. The main current uses of nano-silver relate to antibacterial and anti-odour effects in applications for clothing, domestic appliances such as refrigerators and washing machines, food packaging, cosmetics and personal care products, and health supplements (Products using nanosilver are listed in Appendix 1). It is, however, of note that, although produced in large quantities, nano-silver is not a high-volume nanomaterial yet. This is because of two reasons – it is comparatively much more expensive than some other nanomaterials (typically > $5,000/kg), and it is generally used in very low concentrations (typically 10-20 ppm in cosmetics and personal care products, 20 ppm in health supplements, 50 ppm in fabric coatings, to up to 5% in antibacterial wound dressings).

3.6 Products containing ENPs currently available on the UK market (ENP concentration, emission, & market share data)

Results of the literature search on products containing ENMs and currently available on the UK market are listed in Appendix 1 including type of ENM, source and estimated global production (January 2010). In total 126 products have been identified, of which 15 contain more than one type of nanomaterial (e.g. TiO_2 and C). Therefore the total amount of products increases to 148, if products are listed by individual types of ENM. Each product was given a unique number, so that a product containing 2 or more types of ENMs can easily be identified by the identification number (ID). The types of nanomaterial identified in the 126 products include (number of products in brackets):

Ag (20), Al (1) and Al_2O_3 (3), C (6), C60 (6), Ca peroxide (1), CeO (1), Ceramic (2), ceramide (1 – lipid molecules in the nano-scale), clay (2), Carbon nanotubes (13), Cu (1), Fe2O3 (1), keratin (6), lipid encapsulates (5), micelles (1 - water/oil emulsion droplets in the nano-scale), silazane (1), SiO_2 (14), TiO_2 (12) and Ti (2), Vitamin E capsules (1), ZnO (14), Zr (1). Out of the 148 types of ENPs used in products, 32 could not be identified.

It has to be noted that products only available from abroad and via the internet have not been taken into consideration for two reasons: (1) due to language barriers and the vast amount of products, this could not be achieved within the remit of this project, and (2) it was anticipated that the market penetration in the UK of those products will be negligibly small.

Data on usage scenarios for emissions to wastewater treatment are presented in Table 3.3 and concentrations of engineered nanoparticles in different product types are shown in Table 3.4 (see also Appendix 2). Tables include information on products whose usage is likely to result in release of ENPs to the aqueous environment. Products considered to be disposed of via landfills and unclassifiable products are not included, however, they may need to be considered in future.

Usage and concentration data are necessary to estimate likely concentrations of engineered nanoparticles in raw and treated drinking waters (see Chapter 5). If no information could be obtained for a specific product, data was extrapolated from available information on usage and concentration levels from similar products or usages assuming e.g. that a product type will contain ENPs in a similar concentration independent of the type of ENP. For example, a paint product contains 10% of nano TiO_2 according to a manufacturer's material safety data sheet. Based on this information, it was assumed that paints containing other metal oxide nanoparticles (e.g. nanoFe_2O_3) also contained 10% of ENPs. In instances where the nanoparticle concentration was not specified, data on the typical level of bulk material used in non-nanoproducts was used, if available.

Where data was not available, estimates for ENP concentrations as well as emissions have been calculated based on assumptions detailed in Appendix 3. In Table 3.5, available and estimated market share data is provided. This information was particularly difficult to obtain and is therefore mainly based on assumptions (given in Appendix 4).

Table 3.3. Usage scenarios for emissions to wastewater treatment

Product type	Engineered NP	Emission (g/pc/d)	Reference
car polish/wax	all	0.3	see Appendix 3
clothing	all	89	see Appendix 3
coating (cleaners)	all	110	Technical Guidance Document on RA (2003)
coating (aquarium)	SiO_2	0.002	see Appendix 3; [redacted]
cosmetics	all	0.8	Technical Guidance Document on RA (2003)
cosmetics (conceler)	Al_2O_3	0.06	Technical Guidance Document on RA (2003)
cosmetics (lotion)	ZnO	15	Technical Guidance Document on RA (2003)
food supplement	micelles	0.01	Pravst et al. (2010)
fuel additive	CeO	0.007	see Appendix 3
hair loss treatment	keratin	0.2	see Appendix 3
paint (coating)	all	33	Adams (2005)
sunscreen	all	0.9	Technical Guidance Document on RA (2003); Appendix 3
toothpaste	all	2.8	Technical Guidance Document on RA (2003)
washing machine	Ag	1.375	see Appendix 3

Table 3.4. Available and estimated data on concentrations of engineered nanoparticles in different product types

Product type	Engineered NP	Concentration (%)	Reference
car polish/wax	all	5	http://www.faqs.org/patents/app/20090025508
clothing	Al	0.01	see Appendix 3
clothing	SiO_2	4	Wu et al. (2009)
clothing (sheets, towels)	Ag	0.005	Lee et al. (2003)
clothing (socks)	Ag	0.27	Benn & Westerhoff (2008); see Appendix 2
coating	Ag	0.001-0.1	Boxall et al. (2007)
coating	ceramic	10	Boxall et al. (2007)
coating (paints)	TiO_2	5	Boxall et al. (2007)
coating (aquarium)	SiO_2	100	see Appendix 3
cosmetic	Al_2O_3	3	http://www.freepatentsonline.com/y2005/0074473.html
cosmetic (cream)	encapsulates	4	Mueller et al. (2006)
cosmetic (lotion)	ZnO	6	[redacted]
cosmetics (cream)	C60	0.25	Boxall et al. (2007)
cosmetics	SiO_2	15	http://www.freepatentsonline.com/6335037.html
cosmetics (lipstick)	all	0.3	Boxall et al. (2007)
food supplement	micelles	22	[redacted]
fuel additive	CeO	0.001	Wakefield et al. (2008)
hair loss treatment	keratin	10	http://www.freepatentsonline.com/4369037.html
paint (coating)	all	10	[redacted]
sunscreen (cream)	C60	0.25	Boxall et al. (2007)

Product type	**Engineered NP**	**Concentration (%)**	**Reference**
sunscreen	TiO_2	5-25	CosIng (Internet); [redacted]
sunscreen	ZnO	9-25	CosIng (Internet; based on TiO2); cosmetic database (Internet); [redacted]
toothpaste	all	15	[redacted]
washing machine	Ag	100	see Appendix 3

Table 3.5. Available and estimated data on market shares of different products containing ENPs

Product	Brand	Engineered NP	Market share	Reference
car polish	other	all	<1%	see Appendix 4
car polish[1]	[redacted]	SiO_2	31.7%	see Appendix 4
car polish[2]	[redacted]	SiO_2	25.8%	see Appendix 4
car polish[1]	[redacted]	ZnO	31.7%	see Appendix 4
car polish[2]	[redacted]	ZnO	25.8%	see Appendix 4
coating	Construction (paint, tiles, glass)	all	1%	http://www.observatorynano.eu
coating	Construction (paint, tiles, glass)	ceramic	<0.5%	http://www.observatorynano.eu
coating (aquarium)	[redacted]	SiO_2	<1%	see Appendix 4
cosmetics	[redacted]	C60	0.2%	see Appendix 4
cosmetics	other	all	<1%	see Appendix 4
cosmetics	[redacted]	Al_2O_3	0.3%	see Appendix 4
cosmetics	[redacted]	Al_2O_3	0.0%	see Appendix 4
cosmetics	[redacted]	ceramide	0.4%	see Appendix 4
cosmetics	[redacted]	encapsulates	0.3%	see Appendix 4
cosmetics	[redacted]	encapsulates	0.8%	see Appendix 4
cosmetics	[redacted]	encapsulates	2.5%	see Appendix 4
cosmetics	[redacted]	encapsulates	0.5%	see Appendix 4
cosmetics	[redacted]	SiO_2	0.5%	see Appendix 4
cosmetics	[redacted]	ZnO	2.3%	see Appendix 4
fuel additive	[redacted]	CeO	100%	n/a

Product	Brand	Engineered NP	Market share	Reference
hair loss treatment	[redacted]	keratin	62%	see Appendix 4
paint	Construction (paint, tiles, glass)	all	1%	http://www.observatorynano.eu
sunscreens	[redacted]	C60	<1%	see Appendix 4
sunscreens	all	TiO_2	70%	Nohynek et al. (2007)
sunscreens	all	ZnO	30%	Nohynek et al. (2007)
textiles	all	all	<1%	http://www.observatorynano.eu
toothpaste	[redacted]	Ca	2.6%	see Appendix 4
toothpaste	[redacted]	SiO_4	3.4%	see Appendix 4

[1]same product containing ZnO and SiO_2 ENPs
[2]same product containing ZnO and SiO_2 ENPs

4. Uses likely to result in man-made nanoparticles reaching water sources

In order to provide insight to which kinds of ENP are most likely to reach water sources the products identified in Chapter 3 (Appendix 1) were categorised according to the location of the ENP in the product using the categorisation framework developed by Hansen et al. (2007, 2008a, 2008b). Hansen et al. (2007) distinguish between four different categories of engineered nanoparticles depending on the environment around the ENP (see figure 4.1):

- ENPs bound to the surface of another solid structure;
- ENPs suspended in a liquid;
- ENPs suspended in solids;
- airborne ENPs.

From the information in Chapter 3 and Appendix 1, a total of 126 products were identified. Most of these products fell into the categories clothing, cosmetics, sporting goods, sunscreens and personal care products (Figure 4.2). One product fell within the categories "automotive" as well as "cleaning", raising the number of products by categories to 127 (e.g. Figure 4.2, Table 4.2).

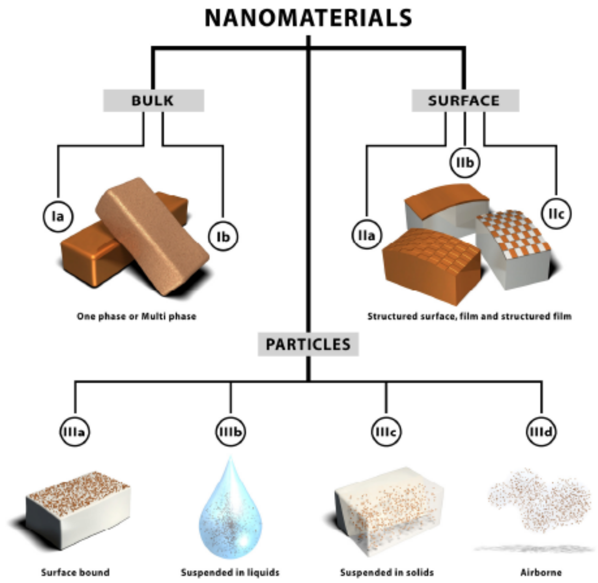

Figure 4.1. The categorisation framework for nanomaterials. The nanomaterials are categorised according to the location of the nanostructure in the material (taken from Hansen et al. 2007).

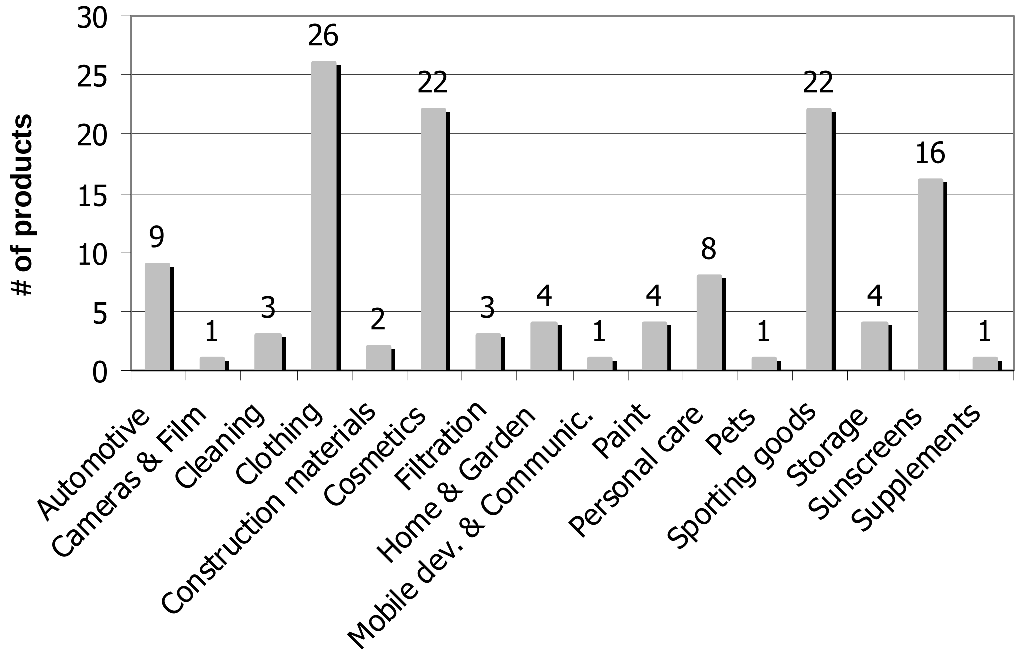

Figure 4.2: Product types identified as containing engineered nanomaterials.

The results of applying this categorisation scheme to the 126 product identified in Chapter 3 are illustrated in Figure 4.3.

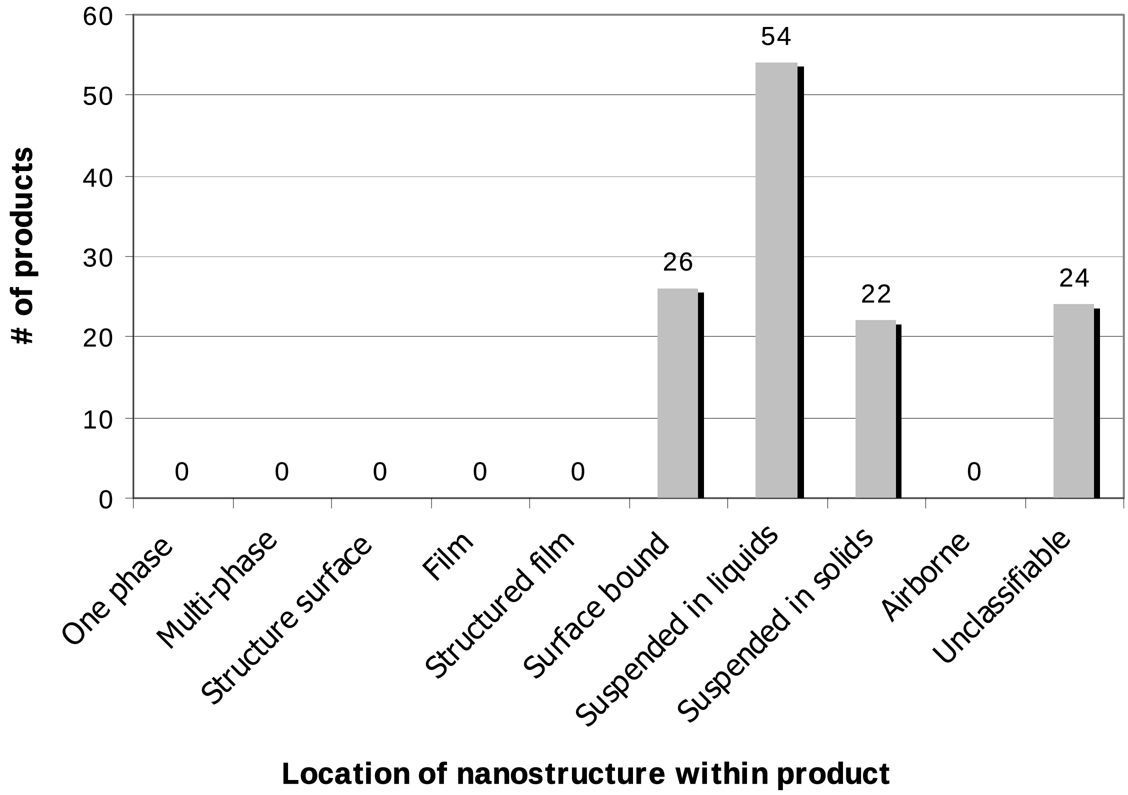

Figure 4.3: Location of the nanostructure used in the various products

It is interesting to note that no products were found to be nanostructured in the bulk or on the surface (see Figure 4.1). All products fall into the particle category. In 43% of the products, the nanoparticles were suspended in liquids. Surface bound nanoparticles and nanoparticles suspended in solids were found in 21% and 17% of the products, respectively. It was not possible to determine the location of the nanostructure in 19% of the products.

Figure 4.4 illustrates the distribution and frequency of different nanomaterials (such as silver, carbon, etc.) in the identified products. In total, 23 different kinds of nanomaterials were used, the most predominate was silver (16%), followed by silica (11%) and zinc oxide (11%), carbon nanotubes (10%) and titanium dioxide (10%). It was not possible to determine the type of nanomaterial used in 32 (25%) products.

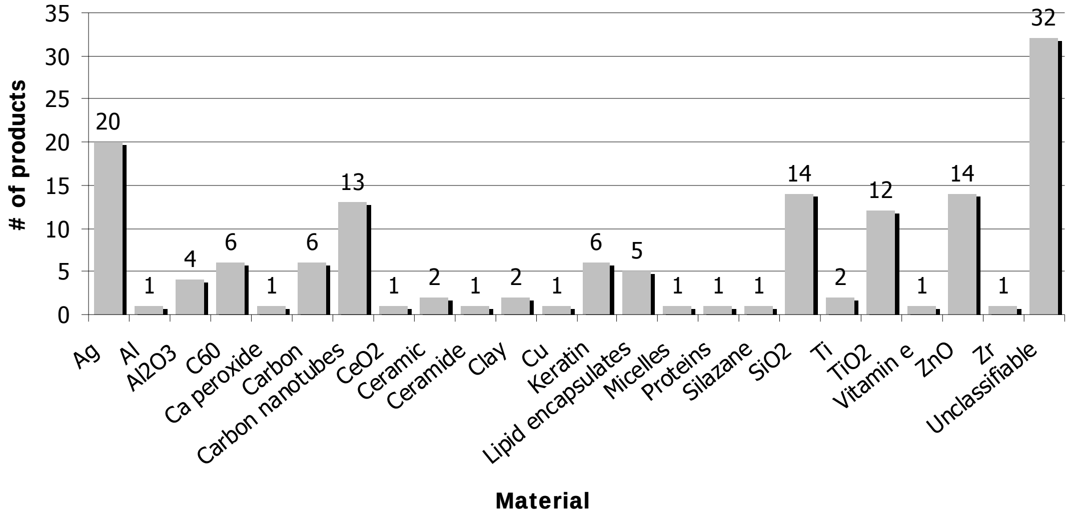

Figure 4.4: Distribution and frequency of various nanomaterial types used in the 126 products

Table 4.1 combines the information given in Figures 4.3 and 4.4, thereby showing the frequency by which a given nanomaterial is used in a given location of the product. Nanosilver is predominately used as surface bound nanoparticles (in 14 out of 20 nanosilver products), whereas zinc oxide is predominately suspended in liquids and titanium dioxide equally often used as surface bound particles and particles suspended in liquids in commercially available products. Five products were found to contain C60 used in some form of liquid suspension, whereas carbon nanotubes were only used in a solid suspension. No product was identified that used nanoparticles in the form of airborne particles.

For the 32 products where it could not be determined what kind of nanomaterial was being used, 28% used the nanomaterial as suspended in liquid, 9% as surface bound nanoparticles and 6% were applied as nanoparticles suspended in solid. For 56% of the products that fell into this category, the location of the nanostructure could not be determined.

According to the location of the ENP, products can be further grouped into three different exposure categories:

1. expected to reach water sources;
2. may reach water sources; and
3. not expected to reach water sources.

Products that would typically fall under the first category are products with "nanoparticles suspended in liquids" or "airborne nanoparticles", whereas products with "surface-bound nanoparticles" and "nanoparticles suspended in solids" would fall into the second and third exposure categories, respectively.

Table 4.1: This table shows the frequency by which a given nanomaterial in used at a given location of the products

Material	Particles Surface bound	Particles Suspended in liquids	Particles Suspended in solids	Particles Airborne	Unclassifiable	Total (#)
Ag	14				6	20
Al	1					1
Al_2O_3		3				3
C60		5	1			6
Ca peroxide		1				1
Carbon	2	3	1			6
Carbon nanotubes			13			13
CeO_2		1				1
Ceramic	2					2
Ceramide		1				1
Clay	1		1			2
Cu	1					1
Fe_2O_3		1				1
Keratin		6				6
Lipid encapsulates		5				5
Micelles		1				1
Proteins		1				1
Silazane		1				1
SiO_2		11	3			14
Ti			2			2
TiO_2	6	6				12
Vitamin E		1				1
ZnO	1	13				14
Zr		1				1
Unclassifiable	3	9	2		18	32
Total (#)	31	70	23	0	24	148
Total (%)	21	47	16		16	

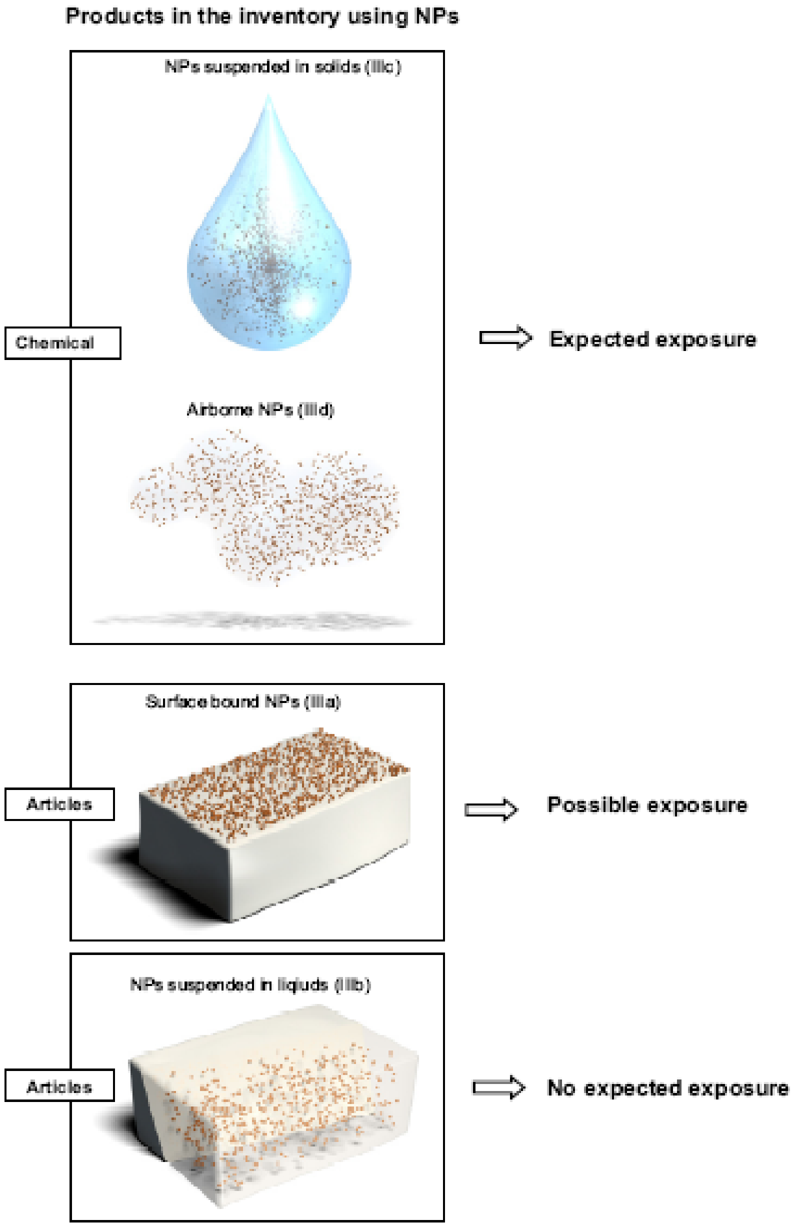

Figure 4.5. Distribution of the products with no, possible and expected exposure within each of the various product categories depending on the location of the nanomaterial in the product (from Hansen et al 2008b).

Sorting the 126 products into exposure categories shows that exposure is expected for most of the nanomaterials. With the exception of carbon nanotubes, for which no exposure is to be expected, the majority of the current uses of nanoparticles in the 126 product fall into categories for which exposure is possible or expected (see Figure 4.6). For the majority of products for which the type of ENP used could not be determined, the potential for exposure, if known, is possible or expected.

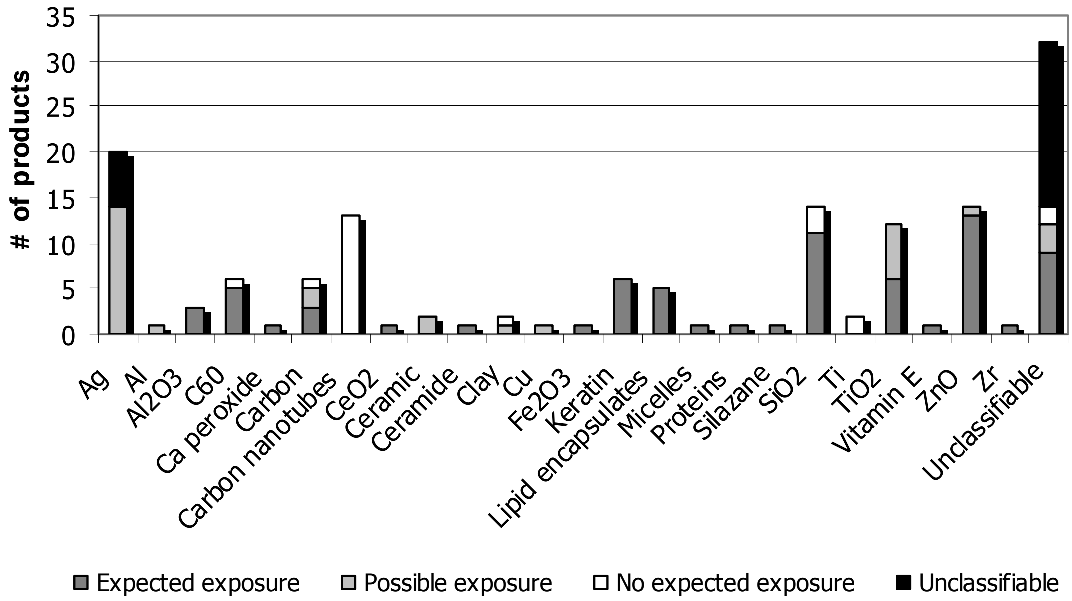

Figure 4.6. Comparison between the exposure categorization and the nanomaterials used

Comparing the product category with the location of the nanoelement (see Table 4.2) shows that most cosmetics and sunscreens used nanoparticles suspended in liquids whereas most sporting goods used nanoparticles suspended in solids. If we assume that products that contain nanoparticles "suspended in liquids" and "airborne nanoparticles" are to be expected to reach water sources, this indicates that nanoparticles used in cosmetics and sunscreens are candidates for nanoparticles that might reach water sources. Nanoparticles used in automotive applications might also be candidates.

Table 4.2: Product category vs. the location of the nanoelement in the product

Product category	#	Surface bound	Suspended in liquids	Suspended in solids	Airborne	Unclassifiable
Automotive	9		8			1
Cameras and Film	1	1				
Cleaning	3	2	1			
Clothing	26	6		3		17
Construction materials	2	1	1			
Cosmetics	22	2	20			
Filtration	3	2				1
Home and Garden	4	4				
Mobile devices and Communication	1					1
Paint	4	2	2			
Personal care	8	3	5			
Pets	1		1			
Sporting goods	22	3		19		
Storage	4					4
Sunscreens	16		16			
Supplements	1		1			
Total	127	26	55	22		24

Not expected to reach water sources
May reach water sources
Expected to reach water sources

If we study what kind of material is used in various product categories (see Table 4.3), one can see that a number of different nanomaterials are being used in cosmetics such as Ag, ZnO, C60, SiO_2, Al_2O_3, Si and Ti. However, we know very little about what kind of material is actually being used in about half of all the cosmetics since we could only classify the nanomaterial being used in 11 out of 22 cosmetic products. For sunscreens TiO_2 and ZnO are the predominant materials used.

Table 4.3: Product category vs. the nanomaterial used in the product

Categories	#	Ag	Al	Al2O3	C60	Ca peroxide	Carbon	Carbon nanotubes	CeO2	Ceramic	Ceramide	Clay	Cu	Fe2O3	Keratin	Lipid encapsulates	Micelles	Proteins	Silazane	SiO2	Ti	TiO2	Vitamin E	ZnO	Zr	Unclassifiable
Automotive	9								1										1	5				6		2
Cameras and Film	1									1																
Cleaning	3	1																		1		2				
Clothing	26	5	1																	3						17
Construction materials	2						1															1				
Cosmetics	22			3	4						1					5		1		3		2		1		2
Filtration	3	3					3						1											1		
Home and Garden	4	4																								
Mobile devices and Com.	1	1																								
Paint	4									1				1								1				1
Personal care	8	1				1									6					2			1	1	1	3
Pets	1																			1						
Sporting goods	22	1			1		2	13				2									2					3
Storage	4	4																								
Sunscreens	16				1																	6		6		4
Supplements	1																1									
Total	127	20	1	3	6	1	6	13	1	2	1	2	1	1	6	5	1	1	1	15*	2	12	1	15*	1	32

*ZnO and SiO_2 ENPs are both used in the one product counted towards the automotive and the cleaning category, therefore the number of products containing ZnO and SiO_2 ENPs sums up to 15 rather than 14.

5. Expected release of engineered nanoparticles to raw and treated drinking water

5.1 Qualitative ranking of consumer products available in the UK containing engineered nanomaterials based on their likelihood to reach drinking water sources

Of the identified 126 products on the UK market that contain ENMs 62 could be ranked qualitatively in terms of their potential to contaminate drinking water, based on the concentration of ENM in the product, product usage, likelihood of environmental exposure and estimated market share for each particle type. Due to the wide range of particle types and consumer products, a ranked list is provided by particle and by product type to allow comparison. Products for which the ENM type is unknown (32) and the ENM location within the product could not be established (24) and/or products for which the major release pattern is predicted to be landfill (35) were excluded (in total 62). Two products (category filtration) could not be included in the ranking due to missing information on usage and ENM concentration in the product.

Data used for the scoring system on market penetration, usage and ENM concentration were collated from scientific publications, patents and manufacturers and product websites (Chapter 3). Nanotechnology is still a highly sensitive area and companies are reluctant to provide any information, therefore for some of the products the required information could not be collated. For these cases, where possible, expert assumptions on usage and ENM concentrations have been made. The detailed approach for these assumptions is outlined in the respective Appendices and Chapter 3. As the collated data is heavily reliant on estimates, a qualitative ranking approach was developed. Depending on NP concentration in the product, usage, market share and likelihood of release, a score has been allocated to each particle and product type:

Route of exposure

Release pattern	Release	Ranking
"down the drain" ("WWT" - waste water treatment plant)	Likely	Included
"hard surface" / "run-off"	Likely	Included
Landfill	Unlikely	Excluded
Unknown	Unclassifiable	Excluded

Scoring of Likelihood of nanomaterials to be released to drinking water

ENPs in product	Release	Score
Suspended in liquids (expected to reach water sources)	Highly likely	1
Surface bound (may reach water sources)	Likely	2
Suspended in solid (not expected to reach water sources)	Unlikely	3
Unknown	Unclassifiable	4

Scoring of Concentrations of nanomaterial in product

Conc. in product in %	Release	Score
0.01-0.1	Very low	4
0.1-1	Low	3
1-10	Medium	2
>10	High	1
Unknown	High	1

Scoring of Emission or usage data

Emission or usage data in g/pc/d	Release	Score
<0.1	Very low	4
0.1-1	Low	3
1-10	Medium	2
10-100	High	1

Scoring of Market share data

Market share in %	Release	Score
<1	Very low	4
1-10	Low	3
10-50	Medium	2
>50	High	1
Unknown (= 100%)	High	1

Low numbers are given for products and NP types with a high risk of contamination of drinking water (high NP concentration, high usage, high likelihood and high market share). For unknown NP concentration in the product and unknown market shares, a conservative assumption has been made and a "high risk" score has been allocated (unknown = high risk = 1).

Based on this approach, the lower the total score of a specific particle and product type, the higher the likely level of contamination of drinking water sources. The results are presented in Table 5.1. It should be noted, that this list is based on individual products although brand and product names have been excluded. More detailed information is provided in Appendix 6.

Table 5.1. Nanomaterials from ENM containing products most likely to reach drinking water sources based on a qualitatively ranking approach

ENP type	Product type	Release pattern	Concentration (qual)	Emission (qual)	Release (qual)	Market share (%)	Score
TiO_2	sunscreen	down the drain	high	low	highly likely	high	6
ZnO	sunscreen	down the drain	high	low	highly likely	medium	7
Ca peroxide	toothpaste	down the drain	high	medium	highly likely	low	7
SiO_2	toothpaste	down the drain	high	medium	highly likely	low	7
ZnO	cosmetics	down the drain	medium	high	highly likely	low	7
keratin fibres	hair loss treatment	down the drain	medium	low	highly likely	high	7
TiO_2 (Mn doped)	sunscreen	down the drain	medium	low	highly likely	high	7
C	paint	run off	medium	high	highly likely	very low	8
Fe_2O_3	paint	run off	medium	high	highly likely	very low	8
SiO_2	car polish	run off	medium	low	highly likely	medium	8
ZnO	car polish	run off	medium	low	highly likely	medium	8
ZnO	sunscreen	down the drain	medium	low	highly likely	medium	8
SiO_2	cosmetics	down the drain	high	low	highly likely	very low	9
Ag	washing machine	down the drain	high	medium	likely	very low	9
ceramic	coating	run off	medium	high	likely	very low	9
TiO_2	coating	run off	medium	high	likely	very low	9
TiO_2	paint	down the drain	medium	high	likely	very low	9
lipid encapsulates	cosmetics	down the drain	medium	low	highly likely	low	9
Proteins	cosmetics	down the drain	unknown (=high)	low	highly likely	very low	9
ceramid nanocapsules	cosmetics	down the drain	unknown (=high)	low	highly likely	very low	9

ENP type	Product type	Release pattern	Concentration (qual)	Emission (qual)	Release (qual)	Market share (%)	Score
Vitamin E nanocapsules	cosmetics	down the drain	unknown (=high)	low	highly likely	very low	9
Micelles	supplement	down the drain	high	very low	highly likely	very low	10
SiO_2	coating	down the drain	high	very low	highly likely	very low	10
Ag	clothing	down the drain	low	high	likely	very low	10
SiO_2	clothing	down the drain	medium	high	unlikely	very low	10
lipid encapsulates	cosmetics	down the drain	medium	low	highly likely	very low	10
silazane	car polish	run off	medium	low	highly likely	very low	10
SiO_2	car polish	run off	medium	low	highly likely	very low	10
ZnO	car polish	run off	medium	low	highly likely	very low	10
Al_2O_3	cosmetics	down the drain	medium	low	highly likely	very low	10
lipid encapsulates	cosmetics	down the drain	medium	low	highly likely	very low	10
CeO	fuel additive	run off	very low	very low	highly likely	unknown	10
C60	cosmetics	down the drain	low	low	highly likely	very low	11
C60	sunscreen	down the drain	low	low	highly likely	very low	11
Al_2O_3	cosmetics	down the drain	medium	very low	highly likely	very low	11
lipid encapsulates	cosmetics	down the drain	medium	very low	highly likely	very low	11
Ag	clothing	down the drain	very low	high	likely	very low	11
Ag	coating	run off	very low	high	likely	very low	11
Al	clothing	down the drain	very low	high	likely	very low	11

It can be concluded that based on this qualitative scoring approach, ENPs contained in sunscreen and personal care products (release pattern "down the drain") are most likely to reach drinking water sources, followed by home and garden products such as paint and car polish (release pattern "run off") and cosmetics (release pattern down the drain"). Lower risks products include some home and garden and personal care products as well as clothing products. It has to be noted that the assumed market share plays a major role within this ranking approach. Among the ENM types most likely to be released to drinking water sources and also showing high production levels (Chapter 3) are titanium dioxide, zinc oxide, silica and silver nanoparticles.

5.2 Fate and behaviour of engineered nanoparticles in the environment

The above screening approach is only based on the characteristics of the product, the concentrations of ENMs in the product and the products usage. In the real environment, particles may be removed in wastewater treatment, dissipate or transform in surface waters or be treated out in drinking water treatment processes. All of these will affect the exposure. In the next sections we provide an overview of the available data on the fate of nanoparticles in different environmental compartments. These data are then used alongside the product usage and concentration data to estimate concentrations of ENPs in drinking water.

5.2.1 Waste water treatment

In general waste water treatment plants (WWTP) are designed to remove solid, organic and microbiological components to prevent or reduce the contamination of receiving water bodies and ultimately drinking water and are subject to compliance standards and regulations (e.g. Urban Waste Water Directive). Wastewater treatment plants include several treatment stages. Typical treatment stages are given in Table 5.2 (taken from Boxall et al. 2007).

Table 5.2. Description of key removal components (taken from Boxall et al. 2007)

Treatment level	Description of removed components
Preliminary	Large solids such as rags, sticks and floatable objects as well as fats oils and greases
Primary	Large suspended solids ad aggregated components
Secondary	Biodegradable organic matter and associated components
Tertiary	Residual suspended solids and colloids
Advanced	Dissolved and colloidal components

The processes most commonly encountered in wastewater treatment include: (1) screens, (2) coarse solids reduction, (3) grit removal, (4) sedimentation, (5) biological treatment and (6) filtration. Most of these processes are physical processes. Other processes can be biological reactions coupled to an adsorption step (Boxall et al. 2007). For further reading, Boxall et al. (2007) give an overview of waste water treatment and discuss treatment processes that can affect particle removal in more detail. Brar et al. (2010) also discuss ENP in waste water and waste water sludge.

The behaviour and fate of ENPs in waste water treatment is of more and more concern to the scientific community, however, to date there is still very few data available. In general, it is believed that ENPs can be removed in wastewater systems for example by (1) interacting with materials used or present in WWTP such as organic matter; (2) particle aggregation and settling (induced e.g. by pH, ionic background); and (3) mechanical/ physical removal of particles entrapped within the mass of the residual solid material (Tiede et al. 2010). This would mean that these ENPs would partition to sewage sludge and consequently could (1) have adverse effects on sludge bacteria necessary for the degradation of other contaminants, or (2) enter the environment via application of sewage sludge to fields. It has to be noted that the interaction of ENPs with materials present in the wastewater can also lead to an increased stabilisation of nanoparticles dispersed in the wastewater. For example, Duncan et al. (2008) reported that fullerenes can interact with natural organic matter, plastic and Teflon as well as with organic contaminants. While no studies were found evaluating if nanoparticles would sorb into biofilms lining pipe walls as well as basins within the treatment plant, based on previous studies on particle entrapment in biofilms, this could be expected. No data was found regarding the sorption of other types of nanoparticles to infrastructure materials. Because of their binding potential, metal-based nanoparticles have been used to assist in removing heavy metals from wastewater (Nurmi et al., 2005; Yavuz et al., 2006).
In addition to ENP concentration, properties such as the dynamics of dispersion, rate of dissolution, characteristics of the nanoparticle aggregates, surface area and surface characteristics are all likely to affect the behaviour and effects of engineered nanoparticles in wastewater systems.

Some data exist that report on the effectiveness of removing nanoparticles using conventional water and wastewater treatment processes (Table 5.3). The fate of silver nanoparticles has been studied by Tiede et al. (2010) and Kiser et al. (2010) in batch experiments (removal 39-97%). Kiser et al. (2010) and Wang et al. (2010) have also studied the removal of fullerol and C60 nanoparticles in batch experiments, finding removal efficiencies ranging from 13-88%. Cerium oxide and copper NPs have been found to be eliminated to 95% from wastewater in a model wastewater treatment plant and in municipal waste waters, respectively (Limbach et al. 2008; Ganesh et al. 2010). Uncoated silica NPs were not found to be removed in simulated primary waste water treatment, whereas coated silica NPs were removed to 71% from wastewater (Jarvie et al. 2010). Data is available for TiO_2 nanoparticles indicating removal efficiencies ranging from 23-95% (Kiser et al, 2009, Kiser et al. 2010, Wang et al. 2010).

Similarly to the fate and behaviour of engineered nanoparticles in the aqueous environment, there are big knowledge gaps regarding the fate of ENPs in waste water treatment. Although a few studies are available that look at the fate or partitioning of nanoparticles in sewage sludge, the validity and applicability of such studies to all nanoparticles is questionable due to the wide range of properties and subsequently behaviour of different types of ENPs, but also due to the different experimental set ups (e.g. different treatment processes, ENP & mixed liquor suspended solid concentrations, contact time, analysis). Without specific details on the actual particles, it will be impossible to predict e.g. the solubility or aggregation of nanoparticles in wastewaters as no minimum removal efficiency percentage seems to exist, valid for all types and sizes of particles.

Where information is available on removal on a specific type of ENP, this has been incorporated in the estimation calculations. For a worst case scenario, and in such cases where no data was available, a 0% removal scenario has also been considered. For a more realistic scenario, based on expert judgement, a 97% removal after O'Melia (1980) has been assumed, which has also been used in environmental ENP concentration predictions by Mueller & Nowack (2008).

Table 5.3 provides collated information on ENP removal in waste water treatment (data highlighted in white and orange has been used in estimation calculations representing worst case scenarios (lowest specific particle removal or 0% removal) as well as a more realistic scenario after O'Melia (1980).

Table 5.3. Collated data on ENP removal in waste water treatment (removal % highlighted in white and orange were applied in ENP concentration estimates).

Particle	Coating	Removal (%)	Removal process	Reference
Ag	coated	90%	Mixed liquor (batch) & Sequencing batch reactors	Tiede et al. 2010; Wang et al. (2010)
Ag	uncoated	97%	Activated sludge (batch)	Kiser et al. 2010
Ag	coated	39%	Activated sludge (batch)	Kiser et al. 2010
Al_2O_3		0%	worst case scenario	No source
C		0%	worst case scenario	No source
Fullerol		13%		Kiser et al. 2010
Fullerol		75%	Sequencing batch reactors	Wang et al. (2010)
C60		88%	Activated sludge (batch)	Kiser et al. 2010
C60		79%	Sequencing batch reactors	Wang et al. (2010)
Ca peroxide		0%	worst case scenario	No source
CeO		95%	Model wastewater treatment plant (OECD)	Limbach et al. 2008
ceramic		0%	worst case scenario	No source
Cu		95%	Municipal waste waters	Ganesh et al. 2010
encapsulates		0%	worst case scenario	No source
Fe_2O_3		0%	worst case scenario	No source
keratin		0%	worst case scenario	No source
silazane		0%	worst case scenario	No source
SiO_2	coated	71%	Simulated primary waste water treatment	Jarvie et al. 2009
SiO_2	uncoated	0%	Simulated primary waste water treatment	Jarvie et al. 2009
TiO_2		23%	Activated sludge (batch)	Kiser et al. 2010
TiO_2		95%	Sequencing batch reactors	Wang et al. (2010)
TiO_2		91%	Wastewater treatment plant	Kiser et al. 2009
QDs		70%	coagulation, flocculation, sedimentation (tap & nanopure water)	Zhang et al (2008)
ZnO		0%	worst case scenario	No source
ALL	<0.1µm	97%	packed bed filters (sand filtration)	O'Melia 1980

5.2.2 Fate and behaviour of engineered nanoparticles in the aquatic environment

The fate and behaviour of engineered nanoparticles in water bodies will have an impact on the potential exposure of drinking waters. The stability of nanoparticles in water depends upon their chemical structure, but also on other particle properties (e.g. size and surface coating) as well as on environmental conditions (e.g. water pH, presence of organic matter, temperature, ionic background and strength). For example, carbon-based nanoparticles such as C60 have been found to form negatively charged colloids that are dispersable in water (Fortner et al., 2005). Also, the water pH was shown to influence the diameter of the C60 aggregates. Fortner et al. (2005) further concluded that C60 aggregates are stable in waters with ionic strengths similar to that of ground water and surface water for up to 15 weeks. Another example is the dispersability of quantum dots with modified surfaces dependent on chemical structure and water pH, but also the presence of specific minerals in water. Zhang et al. (2008) have found among other things that the functional groups attached to the quantum dots prevented aggregation. A more general assessment of our current limited knowledge and understanding of ENP behaviour in water bodies can be found in e.g. Boxall et al. (2007).

However, only very few and highly specific studies on the fate and behaviour of ENPs in the aquatic environment are available and their relevance to the real environment is often highly questionable. Therefore, as our knowledge is still of ENP fate and behaviour in the aqueous environment is still very limited and highly complex, at this point it was not possible to include any considerations on potential ENP losses due to e.g. aggregation, dissolution, sorption processes and/or sedimentation in raw drinking water. A worst case scenario approach had to be adopted assuming that ENPs will not be eliminated in the aquatic environment. This worst case scenario was applied in the calculations to estimate ENP concentrations in raw and treated drinking waters: Due to the lack of data, the potential loss of ENPs in aquatic systems (rivers) was accounted for as 0%, however, with the Equations given in Chapter 5.3, ENP losses in the aquatic environment could potentially be accounted for at a later stage, if new data became available.

5.2.3 Fate and behaviour of engineered nanoparticles in drinking water treatment

Drinking water treatment plants (WTP) are designed to physically remove particles ranging in size from viruses (10 to 100 nm), *Cryptosporium* oocysts (3 to 7 μm), *Giardia* oocysts (8 to 15 μm) and larger organic and inorganic detritus. The primary particle removal processes in water treatment plants involve sedimentation and/or filtration. Each of these processes will be briefly reviewed with relation to the above "traditional" particles as well as ENPs.

Central to any particle removal process are principles of chemistry and fluid mechanics. Decades of research are available regarding these principles and research with ENPs over the past decade indicate they are appropriate for understanding ENP removal during water treatment. Particle surface chemistry affects the tendency of particles to "stick" together (i.e. aggregate), thereby forming larger particles which are more readily settled out of water. Most particles in lakes and rivers have a net negative surface charge (i.e. negative zeta potential), which prevents their aggregation. This is an evolutionary feature of pathogens, so they can be mobile in the environment. During water treatment, chemical coagulants (e.g. aluminium sulphate, ferric chloride, cationic polymers) are added to neutralize the negative charge on particles. Unlike charged particles which repel each other, neutral particles have low electrostatic repulsion and tend to aggregate due to favourable interactions which arise due to van der Waals forces (i.e. dipole-dipole interactions). Thus, in order for aggregation into larger particles to occur, particles must be neutralized and they must combine together to form colloids. To increase the likelihood of collisions between particles, water treatment plants do two things: first, they add metal salts (alum, ferric) that rapidly hydrolyze and precipitate, forming large numbers of small particles, thus increasing the probability that particles collide; second, they provide mixing (i.e. flocculation) that create shear forces (i.e. orthokinetic flocculation) that promote particle-particle collisions. Mixing is conducted for tens of minutes, which also allows smaller particles to move via Brownian motion (i.e. perikinetic flocculation) and collide. Thus, coagulants are used to both neutralize particles in water and form new particles, both of which promote aggregation. Aggregated particles are large in size and most readily settle out of the water column in sedimentation tanks.

Particles that pass through sedimentation systems have already been chemically neutralized by coagulants, and can be readily removed in granular media filters (including sand filters). Fluid mechanics transport particles into filters and promotes collisions with much larger granular media (e.g. size of media is >100 times the diameter of most particles being removed). Collisions between particles in the water and stationary granular media, including media coated with previously deposited particles, leads to efficient removal of particles that were not removed during sedimentation. Similar to flocculation, Brownian forces dominate transport of sub-micron sized particles which shear forces dominate transport of low micron-sized particles to granular media surfaces.

The combination of coagulation, flocculation, sedimentation and filtration is termed "conventional treatment" and represents the majority of water treatment facilities across developed countries, including the UK. In the USA, the USEPA acknowledges through law that conventional treatment plants are capable of physically removing 99.6% (2.5 log) of *Giardia* and 99% (2.0 log) of viruses. These values are in the USEPA Safe Drinking Water Act and represent conservative estimates of physical removal of particles, which when in river or lake water are stable and of similar sizes to single ENPs (e.g. virus size) or aggregates of ENPs.

Research with ENPs has shown that metallic, metal oxide and carbonaceous ENPs can be removed during coagulation, sedimentation and filtration (Chen and Elimelech 2006; Chen and Elimelech 2007; Chen et al. 2006; Jaisi and Elimelech 2009; Jaisi et al. 2008a; Jaisi et al. 2008b; Lecoanet and Wiesner 2004; Mallevialle et al. 1996; Ryan et al. 1999; Westerhoff et al. 2009; Wiesner and Buckley 1996; Zhang 2007; Zhang et al. 2008). Classical colloid theories have been applied to demonstrate that charge neutralization and other well studied mechanisms can predict ENP removal quite well. Despite nearly half a century of mechanistic studies on particle removal in water treatment plants, because of the heterogeneity in particle size and composition there are no widely used mechanistic models that predict accurately their removal during water treatment. A variety of empirical models exist to predict temporal trends. However, the best guidance available, which also serves as a conservative estimate for particle removal, is the USEPA guidelines stated above. Therefore, for conventional treatment plants we apply the minimum ENP removal (most conservative estimate) of 99%.

Other common water treatment plant configurations exist. In North America a common means of treating waters with low particle counts (e.g. lake waters) is direct filtration; direct filtration involves coagulation and flocculation to neutralize particles but does not include sedimentation – filtration is the primary particle removal step.

In the Safe Drinking Water Act, the USEPA acknowledges through law that direct filtration treatment plants are capable of physically removing 99% (2 log) of Giardia and 96.8% (1.5 log) of virus. To our knowledge, direct filtration is not widely practiced in the UK.

Membrane filtration is becoming increasingly common through the UK, EU and USA. Micro and ultra-filtration membranes have nominal pore sizes around 0.1 um (100 nm). With particle neutralization (i.e., coagulation and flocculation) they routinely exceed 99.9% (3 log) removal of virus-sized challenge particles (bacteriaphage) (Laine et al. 2000; Nishijima and Okada 1998; Schafer et al. 2000; Yuasa 1998). Therefore, for an integrated membrane treatment plant we apply the minimum ENP removal of 99.9%.

Other treatment processes commonly used in water treatment plants are not designed to directly removal particles, and thus we provide no added ENP removal by these processes. Powder (PAC) and granular (GAC) activated carbon are added to sorb dissolved pollutants such as pesticides. They likely improve removal of particles, including ENPs, but no direct evidence of this has been shown. Ozone and other chemical disinfectants (e.g. chlorine, advanced oxidation processes) can oxidize surface coatings on ENPs, but proper coagulation for charge neutralization usually accompanies these processes (Lee et al. 2009; Lee et al. 2008). Ultraviolet irradiation is increasingly applied at low dosages for microbial inactivation and is not expected to affect ENP removal. Therefore, no additional benefit of particle removal will be assigned to these processes (ozone, activated carbon, ultraviolet irradiation).

5.3 Estimation of ENP concentrations in raw water and treated drinking water

It is clear from the previous sections that our understanding of the current usage of ENPs is limited and that very little data are available on amounts of ENPs in use and on the market share of ENP containing products as well as their concentration within the product. Therefore in this section we describe algorithms for estimating potential concentrations of ENPs in raw and treated drinking water, based on available data. The algorithms were then applied to predict concentrations of ENPs in raw and treated drinking waters from a range of ENP containing products described in Chapter 3. Results are given in Tables 5.4 to 5.10 and Appendix 7.

Many of the identified ENP containing products (Chapter 3) will be released to the aquatic environment via the sewage system. Products that could not be classified or will be disposed of via landfill have not been considered in this modelling approach. Release patterns of ENPs to the aquatic environment have been identified as: 1) run-off from surfaces or 2) "down the drain". For this modelling approach it has been assumed that both routes of entry will lead to ENPs being released to wastewater and that all wastewater is collected and treated prior re-entering the aquatic environment (rivers). ENP emissions from wastewater treatment plants will then be diluted in the aquatic environment (raw drinking water) before being treated in WTPs (Figure 5.1). A conservative estimate of ENP concentrations in: 1) WWTP effluent and sewage sludge; 2) Receiving waters/WTP influent, and 3) WTP effluent has been obtained using an adaptation of the surface water exposure algorithm developed by the Committee for Medicinal Products for Human Use (CHMP, 2006). This algorithm estimates surface water concentrations based on the concentration of ENP in a product, the amount of product used per capita per day and the market penetration of a product. It assumes that the usage of a product is even over the year and that the sewage system is the main route of entry. A default value of 150 L/capita/d waste water production was adopted based on the OFWAT report (2007) on International comparison of water and sewerage service. A dilution factor in the receiving water bodies was set at the default EU value of 10 (EMEA 2006). Where general market penetration data were available for a product category, this information was used. In cases where market penetration data was estimated per product, all products with their individual market share estimations have been included in the estimates (Appendix 4).

The lack of available data on product usage, ENP concentrations within a product and market penetration as well as on particle fate and behaviour in the aquatic environment and water treatment has made it inevitable to rely on many assumptions. Therefore, due to the many uncertainties underlying the collated data, it was not possible at this stage to justify a higher tier/more complex modelling approach. It should also be noted that although real data and realistic estimations were considered where possible, due to knowledge gaps the approach chosen is a conservative approach assuming that all ENPs in a product (for products classified as "release likely") will end up in the aquatic environment and waste water not considering different usage scenarios (e.g. wiping off).

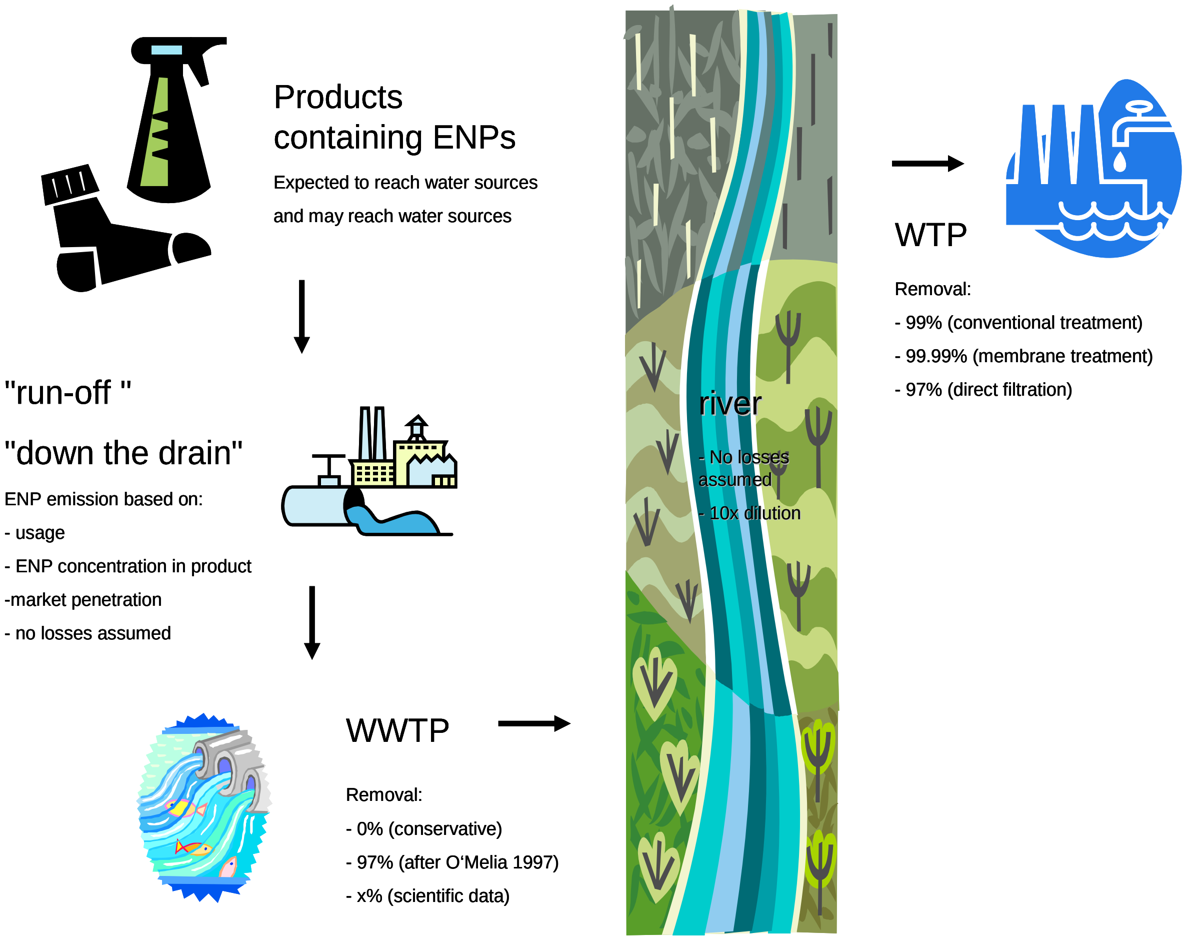

Figure 5.1. Approach to estimate ENP concentrations in raw water and treated drinking water (simplified schematic)

For the estimation of the potential environmental exposure to different ENPs from use and disposal of materials and products of nanotechnologies, models previously developed and applied to predict environmental exposure to ENPs were used. Predicted concentrations have been estimated as total ENP mass concentrations (µg/L) and number concentrations (#/L), where possible (depending on availability of ENP mean diameter), for each particle type (based on the chemical composition of the ENP). The applied equations are given below.

Equation (1)

The ENP effluent concentration (ug/L) from waste water treatment plants was estimated as follows:

$$PEffC_{WWTP} = \frac{C_{ENP}.U_{prod}.(1 - R_{stp}).F_{pen}}{WW_{inhab}}$$

Where:

$PEffC_{WWTP}$ = predicted effluent concentration from WWTP (ug l^{-1})

C_{ENP} = concentration of engineered nanoparticle in product (gNP g^{-1})

U_{prod} = daily usage of product (g $capita^{-1}$ d^{-1})

R_{stp} = fraction of ENP removed during sewage treatment

- *Conservative estimate = 0%*
- *Realistic estimate after O'Melia (1997) = 97%*
- *Available data of particle removal for specific ENP types*

F_{pen} = market penetration of nano-containing product

WW_{inhab} = amount of wastewater produced (l $capita^{-1}$ d^{-1}) (default = 150)

Equation (2)

The predicted ENP concentration in biosolids/sewage sludge was calculated as follows:

$$PBsC_{WWTP} = \frac{C_{ENP}.U_{prod}.F_{pen}}{WW_{inhab}} - \frac{C_{ENP}.U_{prod}.(1 - R_{stp}).F_{pen}}{WW_{inhab}}$$

Where:

$PBsC_{WWTP}$ = predicted concentration in biosolids/sewage sludge (ug l^{-1})

Equation (3)

To predict the environmental concentration of ENPs in surface water or raw drinking water (WTP influent) following equation was applied:

$$PEC_{sw} = \frac{C_{ENP}.U_{prod}.(1 - R_{stp}).(1 - M).F_{pen}}{WW_{inhab}.D}$$

Where:

PEC_{sw} = predicted concentration in surface water/influent NP concentration into WTP (ug l^{-1})

D = dilution factor in the receiving water (default = 10)

M = NP losses in river (removal/transformation) (default = 0%; unknown)

Equation (4)

The ENP effluent concentration in tap water was predicted with the help of this equation:

$$PEffC_{WTP} = \frac{C_{ENP}.U_{prod}.(1-R_{stp}).(1-M).F_{pen}}{WW_{inhab}.D} \times (1-R_{WTP})$$

Where:

$PEffC_{WTP}$ = *predicted concentration in tap water (ug l^{-1})*

R_{WTP} = fraction of ENP removed during drinking water treatment:

- *Conventional treatment = 99%*
- *Membrane treatment = 99.99%*
- *Direct filtration = 97%*

All ENP mass concentrations calculated using the above given equations were then additionally converted to provide ENP particle number concentrations. For this, equation 5 was applied:

Equation (5)

For particle number concentrations (PNC) to be estimated, the mean particle diameter is needed. For those particle types, for which data on ENP size could be determined from the respective product information, the PNC could therefore be derived from the estimated mass concentration in raw and treated drinking waters.

If a size range was given, the smallest value was chosen, so as to provide a worst case scenario (smaller particle size equals highest PNC). If more than two possible particle sizes for a product were found, then PNC calculations are provided for a maximum of two different particle sizes. Firstly, the two most commonly reported particle sizes were chosen. If more than two possible particle sizes for a product were found, but each was only reported once, then the smallest and the biggest reported size were chosen.

Particle number concentrations were calculated using following equations:

$$PNC = \frac{C_{particle}}{M_{particle}}$$

Where:

PNC = particle number concentration (#/L)

$C_{particle}$ *= NP mass concentration (ug/L)*

$M_{particle}$ *= mass per particle (ug/#)*

With:

$$V_{particle} = \frac{\pi \times D^3_{particle}}{6 \times 10^{-21}}$$

Where

$V_{particle}$ *= Volume per particle (cm^3)*

$D_{particle}$ *= Mean NP diameter (nm)*

And:

$$M_{particle} = V_{particle} \times \rho_{particle} \times 1000000$$

Where:

$M_{particle}$ *= mass per particle (ug/#)*

$V_{particle}$ *= Volume per particle (cm^3)*

$\rho_{particle}$ *= Density (g/cm^3)*

The suggested models currently provide 'worst case' estimates of exposure and do not consider stabilisation, dissolution and aggregation in the environment. All compounds and products were included in the estimation of concentrations in raw and treated drinking water using the modelling approach as described above except for those products that were assumed to go to landfill, and unknowns. Concentrations are given as mass concentrations in ug/L, however, where possible particle number concentrations have also been estimated (#/L), based on particle size in the product and material density.

These simulations assume that there are no other sources of the engineered nanoparticle of concern so it is important that they are updated as and when new information becomes available.

Table 5.4. ENP mass concentration estimates for WTP influent and effluents – assuming 0% particle removal in WWTP.

type	removal WWTP	WTP (influent) ug/L	WTP (conventional) ug/L	WTP (membrane) ug/L	WTP (filtration) ug/L
Titanium oxide	0%	1.64E+02	1.64E+00	1.64E-02	5.18E+00
Zinc oxide	0%	6.36E+01	6.36E-01	6.35E-03	2.01E+00
Silica	0%	4.00E+01	4.00E-01	4.00E-03	1.26E+00
Ceramic	0%	3.67E+01	3.67E-01	3.67E-03	1.16E+00
Carbon & C60	0%	2.21E+01	2.21E-01	2.21E-03	6.98E-01
Carbon	0%	2.20E+01	2.20E-01	2.20E-03	6.96E-01
Iron oxide	0%	2.20E+01	2.20E-01	2.20E-03	6.96E-01
Silver	0%	1.07E+01	1.07E-01	1.07E-03	3.39E-01
Keratin	0%	8.27E+00	8.27E-02	8.27E-04	2.61E-01
Ca peroxide	0%	7.17E+00	7.17E-02	7.17E-04	2.27E-01
Encapsulates	0%	1.41E+00	1.41E-02	1.41E-04	4.45E-02
Aluminium and Aluminium oxide	0%	1.29E-01	1.29E-03	1.29E-05	4.08E-03
Silazane	0%	1.00E-01	1.00E-03	1.00E-05	3.16E-03
C60	0%	5.77E-02	5.77E-04	5.77E-06	1.82E-03
Cerium oxide	0%	4.67E-05	4.67E-07	4.67E-09	1.48E-06

Table 5.5. ENP mass concentration estimates for WTP influent and effluents – assuming 97% particle removal in WWTP after O'Melia (1980).

Type	removal WWTP	WTP (influent) ug/L	WTP (conventional) ug/L	WTP (membrane) ug/L	WTP (filtration) ug/L
Titanium oxide	97%	4.91E+00	4.91E-02	4.91E-04	1.55E-01
Zinc oxide	97%	1.91E+00	1.91E-02	1.91E-04	6.03E-02
Silica	97%	1.20E+00	1.20E-02	1.20E-04	3.79E-02
Ceramic	97%	1.10E+00	1.10E-02	1.10E-04	3.48E-02
Carbon & C60	97%	6.62E-01	6.62E-03	6.62E-05	2.09E-02
Carbon	97%	6.60E-01	6.60E-03	6.60E-05	2.09E-02
Iron oxide	97%	6.60E-01	6.60E-03	6.60E-05	2.09E-02
Silver	97%	3.21E-01	3.21E-03	3.21E-05	1.02E-02
Keratin	97%	2.48E-01	2.48E-03	2.48E-05	7.84E-03
Ca peroxide	97%	2.15E-01	2.15E-03	2.15E-05	6.80E-03
Encapsulates	97%	5.92E-02	5.92E-04	5.92E-06	1.87E-03
Aluminium & aluminium oxide	97%	3.87E-03	3.87E-05	3.87E-07	1.22E-04
Silazane	97%	3.00E-03	3.00E-05	3.00E-07	9.49E-05
C60	97%	1.73E-03	1.73E-05	1.73E-07	5.47E-05
Cerium oxide	97%	1.40E-06	1.40E-08	1.40E-10	4.43E-08

Table 5.6. ENP particle number concentration estimates for WTP influent and effluents – assuming 0% particle removal in WWTP.

Type	removal WWTP	Particle size nm	WTP (infl.) #/L	WTP (conv.) #/L	WTP (membr.) #/L	WTP (filtr.) #/L
Silica	0%	10	2.90E+13	2.90E+11	2.90E+09	9.16E+11
Titanium oxide	0%	20	9.24E+13	9.24E+10	9.24E+08	2.92E+11
Iron oxide	0%	10	8.13E+12	8.13E+10	8.13E+08	2.57E+11
Zinc oxide	0%	20	2.71E+12	2.71E+10	2.71E+08	8.56E+10
Titanium oxide	0%	70	2.15E+12	2.15E+09	2.15E+07	6.81E+09
Silver	0%	25	1.25E+11	1.25E+09	1.25E+07	3.95E+09
C60	0%	20	8.00E+09	8.00E+07	8.00E+05	2.53E+08
Zinc oxide	0%	200	2.71E+09	2.71E+07	2.71E+05	8.56E+07
Aluminium & aluminium oxide	0%	50	7.30E+08	7.30E+06	7.30E+04	2.31E+07
Silver	0%	150	5.78E+08	5.78E+06	5.78E+04	1.83E+07
C60	0%	80	1.25E+08	1.25E+06	1.25E+04	3.95E+06
Silica	0%	1000	2.90E+07	2.90E+05	2.90E+03	9.16E+05
Cerium oxide	0%	8	2.44E+07	2.44E+05	2.44E+03	7.72E+05
Aluminium & aluminium oxide	0%	5000	7.30E+02	7.30E+00	7.30E-02	2.31E+01

Table 5.7. ENP particle number concentration estimates for WTP influent and effluents – assuming 97% particle removal in WWTP after O'Melia (1980).

type	removal WWTP	Particle size nm	WTP (infl.) #/L	WTP (conv.) #/L	WTP (memb.) #/L	WTP (filtr.) #/L
Silica	97%	10	8.69E+11	8.69E+09	8.69E+07	2.75E+10
Titanium oxide	97%	20	2.77E+11	2.77E+09	2.77E+07	8.76E+09
Iron oxide	97%	10	2.44E+11	2.44E+09	2.44E+07	7.71E+09
Zinc oxide	97%	20	8.12E+10	8.12E+08	8.12E+06	2.57E+09
Titanium oxide	97%	70	6.46E+09	6.46E+07	6.46E+05	2.04E+08
Silver	97%	25	3.75E+09	3.75E+07	3.75E+05	1.18E+08
C60	97%	20	2.40E+08	2.40E+06	2.40E+04	7.59E+06
Zinc oxide	97%	200	8.12E+07	8.12E+05	8.12E+03	2.57E+06
Aluminium & aluminium oxide	97%	50	2.19E+07	2.19E+05	2.19E+03	6.92E+05
Silver	97%	150	1.73E+07	1.73E+05	1.73E+03	5.48E+05
C60	97%	80	3.75E+06	3.75E+04	3.75E+02	1.19E+05
Silica	97%	1000	8.69E+05	8.69E+03	8.69E+01	2.75E+04
Cerium oxide	97%	8	7.32E+05	7.32E+03	7.32E+01	2.32E+04
Aluminium & aluminium oxide	97%	5000	2.19E+01	2.19E-01	2.19E-03	6.92E-01

Results given in Tables 5.4 and 5.5 suggest that based on ENP mass concentrations and particle removal of 0% or 97%, titanium oxide based nanoparticles are likely to be found in the highest concentrations in raw and treated drinking waters, followed by zinc and silicon based ENPs. Of the more commonly known and discussed ENPs, carbon-based, iron oxide and silver nanoparticles rank in positions 6, 7, and 8, whereas cerium oxide nanoparticles are estimated to be found in the lowest concentrations. Based on PNC estimates, however, silica based ENPs are predicted to be found in the highest particle number concentrations, followed by titanium oxide, iron oxide and zinc oxide based ENPs – for smallest reported particle sizes (Tables 5.6 & 5.7).

Tables 5.9 and 5.10 provide mass and particle number concentration data for particle type specific removal in WWTP for a total of four particle types (TiO_2, Ag, CeO and C60). Here, for mass and particle number concentrations, out of the four considered particle types, titanium dioxide ENPs would account for the highest mass and particle number concentrations (even if only sunscreen products containing TiO_2 are considered), followed by silver ENPs.

The data for predicted environmental concentrations (PEC_{SW}) in receiving water bodies (here: WTP influent concentrations) can be compared to estimates from the scientific literature (e.g. Boxall et al. 2007, Mueller & Nowack 2008, Gottschalk et al. 2009), although only available for a few particle types. In most cases the predicted concentrations are within the same order of magnitude despite the different approaches used (Table 5.8).

To our knowledge, so far no data has been published in the literature on predicted ENP concentrations in treated drinking water.

Table 5.8. Comparison of PEC_{SW} (ug/L) from the scientific literature.

	PEC_{SW} (ug/L)	**PEC_{SW} (ug/L)**	**PEC_{SW} (ug/L)**	**PEC_{SW} (ug/L)**
	Tiede et al. 2010 (97% ENP removal in WWTP)	Boxall et al. 2007 (10% market penetration)	Gottschalk et al. 2009 (Europe)	Mueller & Nowack 2008 (realistic & high emission scenario)
Titanium oxide	4.91	8.4	0.012-0.057	0.7/16
Silica	1.20	2.7		
Zinc oxide	1.91	1.8	0.008-0.055	
C60	0.0017	0.23	0.015-0.12	
Silver	0.32	0.1	0.588-2.16	0.03/0.08
Aluminium and aluminium oxide	0.0039	0.09		

Table 5.9. Predicted ENP mass concentrations in WWTP effluent, sewage sludge, WTP influent and effluent - using particle removal data in WWTP from scientific literature.

type	application	removal WWTP	WWTP effluent ug/L	WWTP biosolids ug/L	WTP influent ug/L	WTP conventional ug/L	WTP membrane ug/L	WTP filtration ug/L
C60	all products	79%	1.21E-01	4.56E-01	1.21E-02	1.21E-04	1.21E-06	3.83E-04
Cerium oxide	all products	95%	2.33E-05	4.43E-04	2.33E-06	2.33E-08	2.33E-10	7.38E-08
Silver	all products	39%	6.54E+01	4.18E+01	6.54E+00	6.54E-02	6.54E-04	2.07E-01
Titanium oxide	all products	23%	1.26E+03	3.76E+02	1.26E+02	1.26E+00	1.26E-02	3.99E+00
Titanium oxide	sunscreens	23%	8.09E+02	2.42E+02	8.09E+01	8.09E-01	8.08E-03	2.56E+00

Table 5.10. Predicted ENP particle number concentrations in WWTP effluent, sewage sludge, WTP influent and effluent - using particle removal data in WWTP from scientific literature.

type	application	removal WWTP	Particle size nm	WWTP effluent #/L	WWTP biosolids #/L	WTP influent #/L	WTP conventional #/L	WTP membrane #/L	WTP filtration #/L
C60	all products	79%	20	1.68E+10	6.32E+10	1.68E+09	1.68E+07	1.68E+05	5.32E+07
C60	all products	79%	80	2.63E+08	9.88E+08	2.63E+07	2.63E+05	2.63E+03	8.31E+05
Cerium oxide	all products	95%	8	1.22E+07	2.32E+08	1.22E+06	1.22E+04	1.22E+02	3.86E+04
Silver	all products	39%	25	7.62E+11	4.87E+11	7.62E+10	7.62E+08	7.62E+06	2.41E+09
Silver	all products	39%	150	3.53E+09	2.25E+09	3.53E+08	3.53E+06	3.53E+04	1.12E+07
Titanium oxide	sunscreens	23%	20	4.56E+13	1.36E+13	4.56E+12	4.56E+10	4.56E+08	1.44E+11
Titanium oxide	sunscreens	23%	70	1.06E+12	3.18E+11	1.06E+11	1.06E+09	1.06E+07	3.37E+09

6. Comparison of estimates for exposure from treated drinking water with estimates for human exposure through other routes

In this chapter the available information on human exposure to nanoparticles from the products identified in Chapter 5 via routes other than drinking water are reviewed. These are then compared to the estimates developed in Chapter 5 to determine the likely importance of the drinking water route of exposure compared to other exposure routes. A combination of the data gathered in Chapters 3 to 5, a focussed review and expert judgement in devising estimates of exposure for the identified products was used. It was aimed to produce ranked estimates of exposure taking account of the likely variation and uncertainty in the estimates. Where there is no suitable data specific for nanoparticles from the products, proxy measures from available data on release of other chemical components from the products were used.

The principal route(s) of exposure and the results of a focussed survey of the toxicology literature were used to inform on the likely exposures and the consequences for each product. The exposure characteristics chosen are consistent with previous studies. Wijnhoven et al (2009) identified three main categories for the exposure assessment of nanomaterials from consumer products (nanomaterial properties, application/frequency and exposure route). A fourth category (release potential) has been included in the present work.

The main output is a 'scorecard' allowing a qualitative comparison of the anticipated relative contributions of nanoparticle hazard and exposure via drinking water sources (designated 'Rating F' developed in chapters 3-5) and non-drinking water sources for the products (designated 'Rating I' developed in this chapter). The difference between ratings provides information on whether drinking water will be the main route of exposure to ENPs and hence how important drinking water will be in terms of possible risks i.e. when Rating F – Rating I is less than zero.

The scorecard is colour coded as follows:

	Exposure risk to nanoparticle is higher from particles in drinking water.
	Exposure risk to nanoparticle is equivalent from particles in drinking water.
	Exposure risk to nanoparticle is lower from particles in drinking water.
	No comparison possible due to unavailability of data from Tasks 3 & 4

6.1 Scoring methodology

Ratings for the products identified in Chapter 3 have been determined in a manner consistent with the qualitative ranking approach adopted in Chapter 5. The rating system sums the assigned scores from the concentration, consumer contact, market penetration and release potential, using a value of 1 for a high score as detailed below.

1. Nanomaterial properties

- chemical identity
- particle shape (spheres, fibres, rods etc)
- location in the product (fixed, free, bound)
- concentration

2. Application / Frequency

- where, how, how much, how long, how many people
- market penetration

3. Release Potential

- ease of release of the nanomaterial from the bulk of the material

Nanomaterial Properties

All relevant properties of the nanomaterials (excluding particle shape and size) gathered in Chapters 3-5 has been used in this approach. A scoring system for the concentration of the nanomaterial in the product, in accordance with Chapter 5, was given as:

Concentration	Range in Product %	Scoring
High	10 – 100	1
Medium	1 – 10	2
Low	0.1 – 1	3
Very Low	< 0.1	4

The location of the nanomaterial within a product, in accordance with Chapter 4, was given as:

Location of Nanomaterial	Description
Surface Bound	**Nanomaterial active at the product-air interface**
Suspended in Liquid	**Nanomaterial unbound within the liquid**
Suspended in Solid	**Nanomaterial embedded / isolated within a solid matrix**

The location of the nanomaterial is used in the consideration of the *likelihood* of consumer contact (Application/Frequency) and Release Potential, as illustrated below.

Application / Frequency

For product application (frequency of use rates for each product per person), a qualitative approach was adopted which aimed to consider the physical nature of the product and the extent of human interaction / contact.

For example, products such as cosmetics, car waxes, clothing, mobile phones and personal care items are all intended to be directly handled by consumers and are therefore scored highly (score = 1). Products such as paints, car shock absorbers and fuel additives are not intended for direct consumer contact but may come into infrequent contact (e.g. splashes, maintenance) and are subsequently scored lower (score = 2). Some products are not intended to come into contact with consumers under normal circumstances (e.g. self cleaning glass) and are scored accordingly (score = 3). The scoring system for application/frequency is summarised below:

Application	Contact	Scoring
Consumer contact intended and likely	High	1
Consumer contact not Intended but possible	Medium	2
Consumer contact not Intended and not likely	Low	3

As part of the application/frequency analysis, the market penetration of the product was also taken into consideration within the rating system. This work was undertaken and scored accordingly in Chapters 3 & 5. Figures derived in these tasks have subsequently been applied within this evaluation. The scoring system for market penetration is summarised below:

Market Penetration	Scoring
High	1
Medium	2
Low	3
Very Low	4

Release Potential

As with the "application/frequency" category, the release potential considers the ease of which the nanomaterial can come into contact with the consumer.

The location of the nanoparticle within the product is one of the most important categories for the estimation of potential exposure. Hansen at al. (2008) described products having nanoparticles suspended in liquids and free airborne nanoparticles as having the greatest expectancy to cause exposure. The products have therefore been scored according to the location of the nanoparticles using the data from Chapter 4:

Nanomaterial Location	Release Potential	Scoring
Suspended in Liquid	Highly Likely	1
Surface Bound	Likely / Unlikely	2
Suspended in Solids	Unlikely	3

6.2 Review of existing data and consideration of exposure routes

Nanomaterial concentrations were supplied as part of Chapter 1 where these were either based on information disseminated by the manufacturer, or assumptions / estimations based on literature searches.

Release potential of the nanomaterials was categorised, where possible, from review of existing published data. Where data could not be found then expert judgement was used to assign scores.

The literature and information search using Pub Med, Google and Google Scholar was conducted by i) industry sector and ii) refined further by the chemistry of the nanomaterial within that particular application, as appropriate. In both cases the literature search focused on data pertaining to the exposure groups noted for either the product or the chemistry. Assessment of the likely exposure routes was based predominately on the physical nature of the product (solid, liquid), its application by the consumer and the location of the nanomaterial within the product (surface bound, suspended in liquid, suspended in solid) as identified in Chapter 5. The categories for potential exposure are given as:

Exposure Routes
Inhalation
Dermal
Ingestion
Combination

Examples of the link between nanomaterial location and primary / secondary exposure routes are given below:

Nanomaterial Location	Primary Exposure Route	Potential Secondary Exposure Route
Suspended in Liquid[1]	**Dermal**	**Inhalation[2]**
Surface Bound	**Dermal**	**Inhalation**
Suspended in Solids	**Dermal**	**Inhalation**

[1] primary route for toothpastes and food supplements is by ingestion.

[2] inhalation exposure from nanomaterials suspended in liquids is related to a secondary application of the product e.g. potential inhalation exposure to dried paint, car fumes.

Where no specific information could be found in the literature, analogous information was sought.

Sector Literature Search

Automotive

Cameras & Film

Cleaning Products

Clothing

Communications

Cosmetics

Filtration

Home & Garden

Paints and Coatings

Sporting Goods

Storage

Sunscreens

Supplements

Personal Care

Nano-material Product Search

Aluminium Oxide

Carbon Nanotubes

Cerium Oxide

Iron Oxide

Silicon Dioxide

Titanium Dioxide

Zinc Oxide

Analysis of exposure potential by Sector & Product was conducted in the following ways:

Automotive

i. Car Polishes, Waxes and Cleaning Products

All of the cleaning related products detailed in Table 6.1 are liquid in nature and are intended to come into direct contact with the consumer during product application. Consumer contact with the product is therefore high as is the potential for direct contact with the nanomaterial suspended in the liquid.

A secondary exposure route can also be considered. Indoor inhalation exposure to cleaning agents is widely reported in the literature (e.g. Heinrich, 2010; Nielsen et al. 2007) where the main focus resides with exposure to volatile organic compounds (VOCs) within the product.

There is currently a lack of literature regarding the potential inhalation exposure to nanomaterial containing cleaning agents in outdoor space. Whilst the nanomaterials detailed in Table 3.1 are not volatile, Nazatoff at al. (2004) reported that inhalable airborne droplets can be produced from aerosol or pump spray delivery systems where some spray droplets remain airborne instead of depositing on the surface of the intended target.

ii. Fuel Borne Catalyst

Cerium oxide is added to diesel fuel at a level of 5 mg/L to reduce fuel consumption, greenhouse gas emission and particulate emissions. The most likely exposure route to the consumer would be through spillages during the filling operation when blow-back from the fuel tank or container when the liquid level is reaching full capacity is possible (HELA, 2009). These instances are likely to be very low in frequency with the quantity of fuel spilled, and available for dermal contact very low.

Exposure potential via inhalation is also a possible route where cerium oxide can enter the atmosphere through vehicle emissions. Park et al. (2008) conducted a study to demonstrate that the addition of the cerium oxide nanomaterial did not alter the intrinsic toxicity of the particles emitted in the exhaust. The study concluded that exposure to nano-sized cerium oxide as a result of addition to diesel fuel at current levels was unlikely to lead to respiratory and cardiac health problems.

Table 6.1. Products, chemistries and exposure potential (automotive sector)

Products Automotive	No.	Nanomaterial Location	Chemistry	$Conc^n$	Exposure Route	Consumer Contact	Potential for Release
[redacted]	21	suspended in liquid	SiO_2	Medium	Dermal	High	Highly likely
			ZnO	Medium	Dermal	High	Highly likely
[redacted]	25	suspended in liquid	ZnO	Medium	Dermal	High	Highly likely
[redacted]	38	suspended in liquid	Silazane	Medium	Dermal	High	Highly likely
			SiO_2	Medium	Dermal	High	Highly likely
			ZnO	Medium	Dermal	High	Highly likely
[redacted]	41	suspended in liquid	SiO_2	Medium	Dermal	High	Highly likely
			ZnO	Medium	Dermal	High	Highly likely
[redacted]	42	suspended in liquid	SiO_2	Medium	Dermal	High	Highly likely
			ZnO	Medium	Dermal	High	Highly likely
[redacted]	72	suspended in liquid	SiO_2	Medium	Dermal	High	Highly likely
			ZnO	Medium	Dermal	High	Highly likely
[redacted]	46	suspended in liquid	N.S.	N.S.	Dermal	High	Highly likely
[redacted]	22	suspended in liquid	CeO	Very Low	Dermal Inhalation	Med - Low	Unlikely
[redacted]	62	suspended in solids	NS	NS	Dermal	Low	Unlikely

N.S. Not Specified

Cleaning

i. Wipes and Cloths

The two wipes listed in Table 6.2 are intended to be used directly by consumers and subsequently have a dermal route for exposure.

Silver nanoparticles have a similar antimicrobial effect as silver ions and silver salts (Kim et al. 2007). For the mechanism to be effective for antimicrobial wipes it is reasonable to assume that the silver nanoparticles are transferred to the surface being wiped and to the hand of the consumer. Consumer contact with the wipe and release potential are therefore both high (note that consumer contact with any nanoparticles transferred from the wipe to the surface has not been considered). Nano titanium dioxide particles in wipes would provide the same potential for release and exposure.

Table 6.2 Products, chemistries and exposure potential (cleaning sector)

Product Clean.	**No.**	**Nanomaterial Location**	**Chemistry**	**Conc^n**	**Exposure Route**	**Consumer Contact**	Potential for Release
[redacted]	2	surface bound	Ag	Very Low	Dermal	High	**Highly likely**
			TiO_2	Medium	Dermal	High	**Highly likely**
[redacted]	**60**	**surface bound**	**TiO_2**	**Medium**	**Dermal**	**High**	**Highly likely**

Clothing

i. Nanoparticles in Textiles

Table 6.3 includes all products listed under clothing although it is recognised that there is a lack of data for the majority of items listed. A rating for these products was therefore not assigned.

If the nanoparticles are not sufficiently bound to the textile, they may be released during wear.

Nanoparticles may be integrated into synthetic fibres (suspended in solids) or applied to the surface of fibres (surface bound) as part of a matrix containing the nanoparticles, surfactant, carrier medium and other ingredients (Samal et al. 2010).

Silver nanoparticles are used for their antimicrobial effect, a sunscreen effect can be achieved with TiO_2 or ZnO whilst a dirt repellent (self cleaning) effect can be achieved with the help of SiO_2 (surface structuring, lotus effect).

The main exposure route to nanoparticles in textiles is not clear from the literature. Wijnhoven et al. (2009) surveyed a panel of seven nano and consumer exposure experts to comment on the expected route of exposure of nanoparticle containing textiles. All seven experts gave dermal exposure as being the expected exposure route where there is a large surface area of contact, intensive contact and where matrix bound nanoparticles may have the potential to be released by sweating.

In contrast the BfR (Federal Institute for Risk Assessment – Information No. 018/2007 (2007)) has stated that the focus on hazard potential in textiles is nano particle abrasion followed by inhalation or oral exposure. Uptake of particles through the skin (dermal exposure) is assumed not to happen due to the size of the abraded particles.

Kohler at al. (2008) described a typical 10% weight loss of garments throughout their lifetime although this will be dependent on the nature of the material and where it is likely that most of the weight loss would occur during the washing process. Chaudhry et al. (2009) anticipated that inhalation exposure to nanoparticle containing fibres would be low and estimated exposure in a worst case scenario (four t-shirts worn over three years with 10% nanomaterial wt/wt) as being in the region of 1 $\mu g/m^3$.

The textiles identified in Tasks 3 & 4 have nanoparticle SiO_2 concentrations lower than 5% whilst nano-silver content is lower than 0.1%. Using the analogy of the estimations postulated by Chaudhry et al. (2009) the potential exposure risk to nanoparticles from these is considered unlikely.

Table 6.3 Products, chemistries and exposure potential (clothing sector)

Products Clothing	No.	Nanomaterial Location	Chemistry	Conc^n	Exposure Route	Consumer Contact	Pot. for Release
[redacted]	76	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	77	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	78	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	79	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	80	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	81	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	82	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	83	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	84	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	85	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	86	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	87	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	88	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**

Products Clothing	**No.**	**Nanomaterial Location**	**Chemistry**	**Concⁿ**	**Exposure Route**	**Consumer Contact**	Pot. for Release
Various Clothing Lines	89	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	90	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	91	N.S.	N.S.	N.S.	Dermal & Inhalation	High	**Unclear**
Various Clothing Lines	92	suspended in solids	SiO_2	medium	Dermal & Inhalation	High	**Unlikely**
Various Clothing Lines	93	suspended in solids	SiO_2	medium	Dermal & Inhalation	High	**Unlikely**
Various Clothing Lines	95	suspended in solids	SiO_2	medium	Dermal & Inhalation	High	**Unlikely**
Business & Sports Socks	13	surface bound	Ag	low	Dermal & Inhalation	High	**Unlikely**
[redacted]	63	surface bound	Ag	low	Dermal & Inhalation	High	**Unlikely**
[redacted]	64	surface bound	Ag	low	Dermal & Inhalation	High	**Unlikely**
[redacted]	65	surface bound	Ag	low	Dermal & Inhalation	High	**Unlikely**
100% cotton clean-sheet	1	surface bound	Ag	very low	Dermal & Inhalation	High	**Unlikely**
Various Clothing Lines	94	surface bound	Al	very low	Dermal & Inhalation	High	**Unlikely**
Men's no-iron chinos	**36**	**N.S.**	**N.S.**	**N.S.**	**Dermal & Inhalation**	**High**	Unclear

N.S. Not Specified

Communications

Table 6.4 has a generic listing for various mobile phone devices where product chemistry and concentration has not been identified in Chapter 5. A qualitative assessment on potential exposure risk was still undertaken based on evidence found in the literature.

The experts solicited in the exposure survey by Wijnhoven et al. (2009) anticipated no dermal or inhalation exposure during use due to the nanoparticles being fixed within a matrix and unlikely to migrate.

Chaudhry et al. (2009) also concluded that routine use of CNT containing lithium-ion batteries (directly or indirectly e.g. contained within mobile phones) would not be anticipated to release CNTs under normal product use.

Table 6.4. Products, chemistries and exposure potential within communications

Product Commun.	No.	Nanomaterial Location	Chemistry	Conc^n	Exposure Route	Consumer Contact	Pot. for Release
Various mobile phones	104	suspended in solids	N.S	N.S	Dermal	High	Unlikely

Construction, Paints and Coatings

i. Coatings and Paints

The application of coatings and paints is not intended to bring the consumer into direct contact with the product although some contact will happen either through routine handling and application of the product (splashes, contact with brushes/rollers etc). Direct dermal contact to free nanoparticles suspended in the liquid would therefore be possible as detailed in Table 6.5.

Potential dermal and inhalation exposure during the product application stage would also be considered high if a spray system was used. Brouwer at al. (2001) identified this possibility but concluded that the level of dermal exposure during spraying operations requires a structured, process-based approach to accurately assess the exposure potential rather than rely on existing dermal exposure models.

Potential inhalation exposure risk to paints and coatings containing nanoparticles may also be present post application. Whilst nanoparticle containing painted surfaces in good condition should not present any exposure potential, peeling, chipping, sanding, chalking or cracking paint (leading to the generation of paint chips and dust) can be considered an inhalation exposure risk as documented by the US Environmental Protection Agency's guidelines on lead in paint (2010).

Vorbau at al. (2009) carried out long term abrasion testing using the Taber Abraser Test method to simulate scratching of parquet coatings by shoes where measurements demonstrated no significant nanoparticle release with only particles in the micrometer size range detected.

Hsu and Chein (2007) simulated the abrasive effect of sunlight, wind, and human contact by using ultraviolet lamps, a fan, and a rubber band in a closed chamber, respectively. Coatings with TiO_2 nanoparticles on wood, polymer and tile were analysed. The coating on tile was found to give rise to the highest nanoparticle emissions where it was assumed that the actions of the test greatly reduced the adhesion forces between the primary TiO_2 particles and the carrier surface. Actual values of concentrations report were very low.

A more significant inhalation exposure risk could be expected from further processing of items treated with nanoparticle containing paints and coatings e.g. sanding. Goehler et al. (2010) characterised nanoparticle release from nanoparticle free and nanoparticle doped surface coatings by the simulation of a sanding process. Results showed a significant generation of nanoparticles during the sanding process, however no significant difference could be observed between coatings containing and not containing nanoparticle additives. TEM analysis concluded that the generated nanoparticles were made up of matrix materials, which contained the embedded additives, rather than release of the free nanoparticle additives.

ii. Self Cleaning Glass

It is highly unlikely that consumers will come into direct contact with nanoparticle surface coated glass. Potential exposure to nanoparticles via dermal contact is therefore seen to be unlikely.

Table 6.5. Products, chemistries and exposure potential (construction, paints & coatings sector)

Product Construction, Paints & Coatings	**No.**	**Nanomaterial Location**	**Chemistry**	**Conc^{n}**	**Exposure Route**	**Consumer Contact**	Potential for Release
A range of surface coatings and paints	3	suspended in liquid	Carbon	Medium	Dermal Inhalation	Medium, Higher if spraying	**Highly likely**
[redacted]	55	surface bound	TiO_2	Medium	Dermal	Low	**Unlikely**
[redacted]	15	suspended in liquid	Ceramic	medium	Dermal Inhalation	Medium, Higher if spraying	**Highly likely**
[redacted]	29	suspended in liquid	Fe_2O_3	medium	Dermal Inhalation	Medium Higher if spraying	**Highly likely**
[redacted]	28	surface bound	TiO_2	medium	Dermal Inhalation	High	**Unlikely**
Interior and exterior paint	30	suspended in liquid	N.S	N.S	Dermal Inhalation	Medium, Higher if spraying	**Highly likely**
[redacted]	**69**	**suspended in liquid**	**SiO_2**	**high**	**Dermal**	**Med – Low**	**Highly likely**

Cosmetics

i. Creams and Lotions

The physical nature and application of cosmetic creams and lotions ensures that there is high consumer dermal contact with the product and a subsequently high exposure as the nanoparticles are deposited directly on to the skin. Both of these aspects are seen to be consistent across all of the products listed in Table 6.6.

The main nanoparticles used in cosmetics are titanium dioxide and zinc oxide for their UV protection, silicon dioxide for its use as a skin conditioning agent, and aluminium hydroxide as an opacifying agent. Fullerenes have reportedly been used in creams for their antioxidative properties whereas nanosomes (liposomes) have been used for several decades where they are used to transport and release moisturising agents to the surface of the skin by means of dissolution. Exposure potential to nanosomes/liposomes, as particles is therefore considered negligible despite high ratings for exposure route, consumer contact and likelihood of release.

Several studies have been undertaken to investigate the potential for nanoparticles contained in cosmetics to penetrate human skin. Titanium dioxide and zinc oxide have been extensively examined due to their strong presence in both cosmetic products and sunscreens where these studies have concluded that they do not penetrate skin. Nanoderm (2007) confirmed these findings and concluded that whilst titanium dioxide could penetrate the upper layers of the skin by mechanical action there was no diffusive transport through the layers. Deep penetration of particles was also noted in the hair follicles but not into vital tissue and would be expected to be excreted.

Schneider et al. (2009) however concluded that the penetration of particulate materials into the skin is a very complex process where slight differences in the treatment of the skin samples, way of application, cleaning/rinsing procedures, hydration state may contribute to altered penetration behaviour whilst detection methods may also influence the results. It's clear that a well established protocol needs to be defined in order to compare results from different studies.

The experts surveyed by Wijnhoven et al. (2009) also commented on the high dermal exposure to nanoparticles in cosmetics and also noted the potential of inhalation exposure if liquid products were applied by a spray mechanism.

Table 6.6 Products, chemistries and exposure potential (cosmetics sector)

Product Cosmetics	No.	Nanomaterial Location	Chemistry	Conc^{n}	Exposure Route	Consumer Contact	Potential for Release
[redacted]	34	suspended in liquid	SiO_2	high	Dermal	High	**Highly likely**
Various cosmetics	96	suspended in liquid	SiO_2	high	Dermal	High	**Highly likely**
[redacted]	126	suspended in liquid	SiO_2	high	Dermal	High	**Highly likely**
[redacted]	5	suspended in liquid	Lipid	medium	Dermal	High	**Highly likely**
[redacted]	14	suspended in liquid	AlO	medium	Dermal	High	**Highly likely**
[redacted]	16	suspended in liquid	AlO	medium	Dermal	High	**Highly likely**
[redacted]	33	suspended in liquid	Lipid	medium	Dermal	High	**Highly likely**
[redacted]	50	suspended in liquid	Lipid	medium	Dermal	High	**Highly likely**
[redacted]	51	suspended in liquid	AlO	medium	Dermal	High	**Highly likely**
various cosmetics	97	suspended in liquid	lipid	medium	Dermal	High	**Highly likely**
Various cosmetics [redacted]	99	suspended in liquid	ZnO	medium	Dermal	High	**Highly likely**
[redacted]	8	suspended in liquid	N.S.	N.S.	Dermal	High	**Highly likely**
[redacted]	33	suspended in liquid	C60	low	Dermal	High	**Highly likely**

Product Cosmetics	**No.**	**Nanomaterial Location**	**Chemistry**	**Conc^n**	**Exposure Route**	**Consumer Contact**	Potential for Release
[redacted]	35	suspended in liquid	C60	low	Dermal	High	**Highly likely**
[redacted]	58	suspended in liquid	N.S.	N.S.	Dermal / ingestion	High	**Highly likely**
[redacted]	61	suspended in liquid	N.S.	N.S.	Dermal	High	**Highly likely**
Various cosmetics	98	suspended in liquid	C60	low	Dermal	High	**Highly likely**
Various cosmetics [redacted]	102	suspended in liquid	Ceramid	unknown	Dermal	High	**Highly likely**
[redacted]	125	suspended in liquid	C60	low	Dermal	High	**Highly likely**
Various cosmetics [redacted]	101	suspended in liquid	Lipid	medium	Dermal	High	**Highly likely**
[redacted]	11	suspended in liquid	Proteins	unknown	Dermal	High	**Highly likely**
Various cosmetics [redacted]	100	suspended in liquid	Vitamin E	unknown	Dermal	High	**Highly likely**
[redacted]	**56**	**N.S.**	**N.S.**	**unknown**	**unknown**	**unknown**	**unknown**

N.S. Not Specified

Filtration

Wijnhoven et al. (2009) reported the use of alumina and lanthanum in water purification systems where consumer contact would be considered as being low. Titanium dioxide was identified as being used in air filtration systems where the nanoparticles were stated as being fixed in a matrix. Consumer contact and potential exposure are therefore regarded as being very low.

Nano-silver was not specifically identified in this application by Wijnhoven but can be found in both water and air filtration devices as advertised by [redacted] and others (refer to section 3.1.8 – home and garden). Dermal exposure to nano-silver could be anticipated during maintenance and cleaning of the filter cartridges but this would be anticipated as being very low.

The products listed in Table 6.7 have neither the chemistry nor the concentration of nanoparticle detailed. A qualitative assessment on the exposure risk was therefore carried out based on the comments noted above.

Table 6.7. Products, chemistries and exposure potential (filtration devices sector)

Product Home & Garden	**No.**	**Nanomaterial Location**	**Chemistry**	**Conc^n**	**Exposure Route**	**Consumer Contact**	Potential for Release
[redacted]	6	N.S.	N.S.	N.S.	Dermal	Low	**Unlikely**
[redacted]	7	N.S.	N.S.	N.S.	Dermal	Low	**Unlikely**
Various Air conditioning units	**75**	**N.S.**	**N.S.**	**N.S.**	**Dermal**	**Low**	**Unlikely**

Home and Garden

Silver nanoparticles have been used as an anti-microbial technology in washing machines, refrigerators, air conditioners, air purifiers and vacuum cleaners from 2003 ([redacted]

[redacted]). [redacted] is a trademark name introduced by [redacted] in April 2003, the [redacted] washing machine, as listed in Table 6.8, is a [redacted] product.

i. Washing Machines

[redacted] state that 400 billion nano silver ions are released into each wash which bind to the fabric fibres and give up to an additional 30 days of anti-bacterial effect with enough silver in the product to protect for 10 years ([redacted] – Accessed Sept.2010).

ii. Vacuum Cleaners

The use of nano-silver in vacuum cleaners is described by [redacted] as providing fresh air through an anti-bacterial effect. The silver nanoparticles (1-100nm) are described as being embedded within the filtration system. The filter is designed to be easily removed for cleaning where it is rinsed with water ([redacted] product description – accessed Sept.2010). It would therefore be plausible that silver ions could be created through cleaning resulting in dermal exposure.

iii. General

Christensen et al. (2010) investigated the feasibility of conducting a human risk assessment for nano-silver based on a review of open literature. The study concluded that no quantitative data could be identified that estimated either occupational or consumer inhalation or dermal exposure to nano-silver whilst acknowledging that, especially consumers must be exposed to nano-silver due to its widespread use in consumer products. The study recommended further activities which would generate exposure data for consumer inhalation, dermal and oral exposure.

The study by Wijnhoven et al. (2009) did not identify the use of nano-silver in various household appliances as part of its study relating to nanoparticle exposure in consumer products.

Table 6.8. Products, chemistries and exposure potential (home & garden sector)

Product Home & Garden	No.	Nanomaterial Location	Chemistry	Conc^n	Exposure Route	Consumer Contact	Potential for Release
Various Washing Machines	122	surface bound	Ag	High?	Dermal	High	**Highly Likely**
[redacted]	123	surface bound	Ag	High?	Dermal	High	**Highly Likely**
[redacted]	17	N.S.	N.S.	N.S.	Dermal	Low	**Low**
Various Vacuum Cleaners	121	N.S.	N.S.	N.S.	Dermal	Low	**Low**
[redacted]	59	N.S.	N.S.	N.S.	Unclear	Unclear	**Unclear**
Various Refrigerators	105	N.S.	N.S.	N.S.	Unclear	Unclear	**Unclear**
Various Refrigerators	106	N.S.	N.S.	N.S.	Unclear	Unclear	**Unclear**
Various Refrigerators	**107**	**N.S.**	**N.S.**	**N.S.**	**Unclear**	**Unclear**	**Unclear**

N.S. - Not Specified

Personal Care

i. Toothpastes

Nano-calcium in the form of hydroxyapatite (product number 68, Table 6.9) is used in toothpaste to form a protective film across the tooth and to help repair the tooth enamel. The experts included in the study of Wijnhoven et al. (2009) identified hydroxyapatite as having high oral exposure where the degree of risk would be dependent on the passage of the material through the gut.

No information could be sourced detailing consumer exposure to nano hydroxyapatite through ingestion.

ii. Hair Treatments

Keratin is a protein which makes up approximately 90% of human hair.

Nanomolecular keratin is marketed as a means of replacing the hair's damaged natural keratin. Phillips (2009) reports nano keratin to be bioactive and solubilised allowing easy penetration of the epidermis, although no scientific evidence could be found to support this statement.

iii. Sunscreens

The use of nano TiO_2 and ZnO in sunscreens is consistent with their use in cosmetics where the materials provide a high level of UV protection.

Sadrieh et al. (2010) conducted experiments to examine dermal penetration of nano and sub micron TiO_2 containing sunscreens. Their findings indicated that there is no significant penetration of TiO_2 through the intact normal epidermis and are consistent with conclusions reported from the EU Nanoderm project.

Osmond and McColl (2009) conducted an analysis of the potential exposure and hazard of ZnO nanoparticles used in modern sunscreens. Whilst concluding that the majority of studies supported the view that particles of zinc oxide in sunscreen are not expected to penetrate healthy human skin, they recommended that further work needs to be carried out to investigate the impact of less healthy skin and the long-term use on the skin-penetrability of ZnO nanoparticles as well as the effect of incidental ingestion via hand to mouth transfer and from the use of lip balms.

The analysis also highlighted the photocatalytic behaviour of both TiO_2 and ZnO and the current lack of data on free radical generation on the surface of skin or in hair follicles. The inherent photocatalytic activity of ZnO increases as particle size decreases (Park and Kang 1997; Casey et al. 2006) and can also be influenced by particle morphology and method of preparation (Wang et al. 2007). Whilst coated and uncoated ZnO particles were shown to be photo-stable and non-photocatalytic (Mitchnick et al. 1999), ZnO particles extracted from commercial sunscreens have been shown to be photocatalytically *in vitro* (Rampaul et al. 2007). Similarly TiO_2 and ZnO nanoparticles present in several sunscreens were identified as the initiators of accelerated weathering of surface coatings on roofs through free radical driven degradation. The nanoparticles were transferred to the surface from sunscreen used by the workers working on the roof (Barker and Branch 2008).

Gulson et al. (2010) carried out a study where they exposed a group of humans (n=20) to sunscreens containing 19nm and >100nm ZnO nanoparticles over 5 days using enriched ZnO (^{68}Zn). All subjects exhibited small increases in the level of the tracer in blood and urine samples although it could not be ascertained as to whether the ^{68}Zn had been absorbed as ^{68}ZnO particles, soluble $^{68}Zn^{2+}$ ions or both. Zinc is the second most abundant trace-metal in the body and present in all organs, tissues and fluids (St. Croix et al. 2005; Rostan et al. 2002) but, where it is known that should intracellular levels shift too far in either direction, zinc can become harmful to the cell (Krones et al. 2005; St. Croix et al. 2005; Wiseman et al. 2006).

Table 6.9. Products, chemistries and exposure potential (personal care sector)

Product Personal Care	**No.**	**Nanomaterial Location**	**Chemistry**	**Conc^{n}**	**Exposure Route**	**Consumer Contact**	Potential for Release
[redacted]	68	suspended in liquid	Calcium	high	Ingestion	High	**Highly likely**
[redacted]	12	suspended in liquid	SiO_2	high	Ingestion	High	**Highly likely**
[redacted]	39	suspended in liquid	keratin	medium	Dermal/ Inhalation	High	**Highly likely**
[redacted]	39	suspended in liquid	keratin	medium	Dermal/ Inhalation	High	**Highly likely**
[redacted]	39	suspended in liquid	keratin	medium	Dermal/ Inhalation	High	**Highly likely**
[redacted]	39	suspended in liquid	keratin	medium	Dermal/ Inhalation	High	**Highly likely**
[redacted]	39	suspended in liquid	keratin	medium	Dermal/ Inhalation	High	**Highly likely**
[redacted]	39	suspended in liquid	keratin	medium	Dermal/ Inhalation	High	**Highly likely**

Product Personal Care	**No.**	**Nanomaterial Location**	**Chemistry**	**Conc^{n}**	**Exposure Route**	**Consumer Contact**	Potential for Release
[redacted]	32	N.S.	N.S.	N.S.	Dermal	High	**Highly likely**
[redacted]	40	suspended in liquid	N.S	N.S	Dermal	High	**Likely**
[redacted]	4	N.S.	N.S.	N.S.	Dermal	High	**Unclear**
[redacted]	37	N.S.	N.S.	N.S.	Dermal	High	**Unclear**
[redacted]	26	N.S.	N.S.	N.S.	Dermal	High	**Unclear**
[redacted]	54	suspended in liquid	TiO_2 (Mn)	high	Dermal/ Inhalation	High	**Highly likely**
Various Sunscreens	108	suspended in liquid	TiO_2	high	Dermal/ Inhalation	High	**Highly likely**
Various Sunscreens	109	suspended in liquid	TiO_2	high	Dermal/ Inhalation	High	**Highly likely**
Various Sunscreens	110	suspended in liquid	ZnO	high	Dermal/ Inhalation	High	**Highly likely**
Various Sunscreens	111	suspended in liquid	N.S.	high	Dermal/ Inhalation	High	**Highly likely**
Various Sunscreens	112	suspended in liquid	N.S.	high	Dermal/ Inhalation	High	**Highly likely**
Various Sunscreens	113	suspended in liquid	N.S.	high	Dermal/ Inhalation	High	**Highly likely**
Various Sunscreens	114	suspended in liquid	TiO_2	high	Dermal/ Inhalation	High	**Highly likely**
Various Sunscreens	115	suspended in liquid	ZnO	high	Dermal/ Inhalation	High	**Highly likely**
Various Sunscreens	117	suspended in liquid	ZnO	high	Dermal/ Inhalation	High	**Highly likely**

Product Personal Care	**No.**	**Nanomaterial Location**	**Chemistry**	**Conc^{n}**	**Exposure Route**	**Consumer Contact**	Potential for Release
Various Sunscreens	119	suspended in liquid	ZnO	high	Dermal/ Inhalation	High	**Highly likely**
Various Sunscreens	120	suspended in liquid	TiO2	high	Dermal/ Inhalation	High	**Highly likely**
[redacted]	67	suspended in liquid	TiO_2 (Mn)	medium	Dermal/ Inhalation	High	**Highly likely**
Various Sunscreens	116	suspended in liquid	ZnO	medium	Dermal/ Inhalation	High	**Highly likely**
Various Sunscreens	118	suspended in liquid	ZnO	medium	Dermal/ Inhalation	High	**Highly likely**
Various Sunscreens	120	suspended in liquid	C60	low	Dermal/ Inhalation	High	**Highly likely**
[redacted]	53	N.S.	N.S.	N.S.	Dermal/ Inhalation	High	**Highly likely**
[redacted]	**66**	**suspended in liquid**	**CoEnzyme**	**high**	**Ingestion**	**High**	**Highly likely**

Sporting Goods

As can be noted from Table 6.10, there is a lack of information from the product suppliers as to both the chemical nature and content of nanomaterial within the products.

Wijnhoven at al. (2009) identified sporting goods as a category indicating as carbon nanotubes (CNTs) as the particle of most use. The experts commented that there would be no direct exposure to nanoparticles as they would be isolated in a matrix and unable to leach out. They also commented that the category was too specific.

Chaudhry et al. (2009) also concluded that CNTs would not be expected to be released under normal handling of CNT containing (epoxy)nanocomposites.

Despite the lack of information regarding the nature of the products it is reasonable to postulate that exposure potential to the contained nanoparticles is very low.

Table 6.10 Products, chemistries and exposure potential (sporting goods sector)

Product Sporting Goods	No.	Nanomaterial Location	Chemistry	Conc^n	Exposure Route	Consumer Contact	Potential for Release
[redacted]	10	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
[redacted]	20	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
[redacted]	23	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
[redacted]	24	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
Golf clubs	27	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
[redacted]	31	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
[redacted]	43	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
[redacted]	44	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
[redacted]	45	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
[redacted]	47	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
[redacted]	48	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
[redacted]	49	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**

Product Sporting Goods	**No.**	**Nanomaterial Location**	**Chemistry**	**Conc^{n}**	**Exposure Route**	**Consumer Contact**	Potential for Release
[redacted]	52	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
[redacted]	57	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
Tennis Rackets	70	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
Tennis Racket	71	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
[redacted]	73	N.S.	N.S.		Dermal	High	**Unlikely**
various cycle components	103	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
[redacted]	124	N.S.	N.S	N.S	Dermal	High	**Unlikely**
Bath and Sports Towels	9	surface bound	Ag	Very low	Dermal	High	**Likely**
[redacted]	18	N.S.	N.S.	N.S.	Dermal	High	**Unlikely**
Different bicycle parts [redacted]	**19**	**N.S.**	**N.S.**	**N.S.**	**Dermal**	**High**	**Unlikely**

N.S. Not Specified

6.3 Qualitative comparison of nanoparticle exposure (inhalation, dermal and oral) against exposure from treated drinking water

As described in the introduction, the main output of this chapter is a "scorecard" allowing for a qualitative comparison of the anticipated relative contributions of nanoparticle exposure via drinking water sources and non-drinking water sources for the products derived in Chapter 3. The scorecard is colour coded as follows:

(red, horizontal lines)	**Exposure risk to nanoparticle is higher from particles in drinking water.**
(light blue, vertical lines)	**Exposure risk to nanoparticle is equivalent from particles in drinking water.**
(light green, diagonal lines)	**Exposure risk to nanoparticle is lower from particles in drinking water.**
(grey, grid)	**No comparison possible due to unavailability of data from Tasks 3 & 4**

Automotive

The estimated exposure risk to consumers from dermal contact with car waxes, polishes and shampoos is considered to be greater than the exposure risk anticipated through drinking water.

The high exposure ranking of these types of products, as detailed in Table 6.11, is derived from the relatively high concentration of nanomaterial within the product, the high level of contact between the consumer and the product and the ease of which the nanomaterial can come into direct contact with the consumer.

Table 6.11. Comparative Exposure Ratings for Products (automotive sector)

Products Automot.	No.	N.P	Conc. Rating	Contact Rating	Release Potential Rating	Market Penetr.	Rating F	Rating I	Δ Rating F - I
[redacted]	21	SiO_2	2	1	1	4	10	8	2
		ZnO	2	1	1	4	10	8	2
[redacted]	25	ZnO	2	1	1	N.S	6	4	2
[redacted]	38	Silazane	2	1	1	4	10	8	2
		SiO_2	2	1	1	4	10	8	2
		ZnO	2	1	1	4	10	8	2
[redacted]	41	SiO_2	2	1	1	2	8	6	2
		ZnO	2	1	1	2	8	6	2
[redacted]	42	SiO_2	2	1	1	4	10	8	2
		ZnO	2	1	1	4	10	8	2
[redacted]	72	SiO_2	2	1	1	2	8	6	2
		ZnO	2	1	1	2	8	6	2
[redacted]	46	N.S.	5	1	1	N.S.	No Data	7	
[redacted]	22	CeO	4	2	3	1	10	10	0
[redacted]	**62**	**NS**	**5**	**3**	**3**	**N.S.**	**No Data**	**11**	

Cleaning

The estimated exposure risk to consumers from dermal contact with cloths and wipes is considered to be higher than the exposure risk anticipated through drinking water. The higher exposure ranking of these types of products, as detailed in Table 6.12, is derived from the relatively high concentration of nanomaterial within the product, the high level of contact between the consumer and the assumption made (from literature searches) that the nanomaterials are readily transferred from the surface by touch.

Table 6.12. Comparative Exposure Ratings for Products (cleaning sector)

Products Clean.	**No.**	**N.P**	**Conc. Rating**	**Contact Rating**	**Release Potential Rating**	**Market Penetr.**	**Rating F**	**Rating I**	Δ Rating F - I
[redacted]	2	Ag	4	1	1	4	11	10	1
		TiO_2	2	1	1	4	9	8	1
[redacted]	**60**	**TiO_2**	**2**	**1**	**1**	**4**	**9**	**8**	1

Clothing

For the products considered in Table 6.13, the estimated exposure risk to consumers from dermal contact with clothes is considered in general to be lower than the exposure risk anticipated through drinking water.

Despite the relatively high concentrations of nanomaterials that can be in textiles, they are typically bound within a matrix and unlikely to come into direct contact with the consumer during wear and tear as highlighted previously. Comparative exposure risk could not be assessed for the majority of products due to a lack of data.

Table 6.13. Comparative Exposure Ratings for Products (clothing sector)

Products Clothing	No.	N.P	Conc. Rating	Contact Rating	Release Pot. Rating	Market Penetr.	Rating F	Rating I	Δ Rating F - I
[redacted]	76	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	77	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	78	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	79	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	80	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	81	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	82	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	83	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	84	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	85	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	86	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	87	N.S.	2	1	3	N.S.	No Data	6	

Products Clothing	**No.**	**N.P**	**Conc. Rating**	**Contact Rating**	**Release Pot. Rating**	**Market Penetr.**	**Rating F**	**Rating I**	Δ Rating F - I
Various Clothing Lines	88	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	89	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	90	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	91	N.S.	2	1	3	N.S.	No Data	6	
Various Clothing Lines	92	SiO_2	2	1	3	4	10	10	0
Various Clothing Lines	93	SiO_2	2	1	3	4	10	10	0
Various Clothing Lines	95	SiO_2	2	1	3	4	10	10	0
Business & Sports Socks	13	Ag	3	1	3	4	10	11	-1
[redacted]	63	Ag	3	1	3	N.S.	6	7	-1
[redacted]	64	Ag	3	1	3	N.S.	6	7	-1
[redacted]	65	Ag	3	1	3	4	10	11	-1
[redacted]	1	Ag	4	1	3	4	12	11	-1
Various Clothing Lines	94	Al	4	1	3	4	12	11	-1
Men's no-iron chinos	**36**	**N.S.**	**N.S.**	**1**	**3**	**N.S.**	**No Data**	**-**	

Communications

No comparisons could be made within the communications sector due to insufficient information.

Information gained from the literature however would suggest that consumer exposure to nanomaterials in this sector would be very low due to the lack of direct contact between consumer and the nanomaterial as well as the nanomaterial being embedded within a matrix and subsequently not freely available for direct exposure via either the dermal or inhalation routes.

Table 6.14. Comparative Exposure Ratings for Products (communications)

Products	No.	N.P	Conc. Rating	Contact Rating	Release Potential Rating	Market Penetr.	Rating F	Rating I	Δ Rating F - I
Various mobile phones	104	N.S	N.S	1	3	N.S.	No data	No data	

Construction, Paints and Coatings

The estimated exposure risk to consumers from dermal contact with paints and coatings is seen to be lower than the exposure risk anticipated through drinking water as detailed in Table 6.15.

Despite the products being in liquid form and the nanomaterial dispersed in the liquid, the lower scores are derived from the low level of direct consumer contact with the product.

Table 6.15. Comparative Exposure Ratings for Products (construction, paints & coatings sector)

Products Paints and Coatings	No.	N.P	Conc. Rating	Contact Rating	Release Potential Rating	Market Penetr.	Rating F	Rating I	Δ Rating F - I
A range of surface coatings and paints	3	Carbon	2	2	1	4	8	9	-1
[redacted]	55	TiO_2	2	3	3	4	9	12	-3
[redacted]	15	Ceramic	2	2	1	4	9	9	0
[redacted]	29	Fe_2O_3	2	2	1	4	8	9	-1
[redacted]	28	TiO_2	2	2	3	4	9	11	-2
Interior and exterior paint	30	N.S	2	2	1	N.S.	No Data	5	
[redacted]	**69**	**SiO_2**	**1**	**2**	**1**	**4**	**10**	**8**	2

Cosmetics

The estimated exposure risk to consumers from dermal contact with cosmetic products is considered to be greater than the exposure risk anticipated through drinking water.

The high exposure ranking of these types of products, as detailed in Table 6.16, is derived from the relatively high concentration of nanomaterial within the product, the high level of contact between the consumer and the product and the ease of which the nanomaterial can come into direct contact with the consumer.

Table 6.16. Comparative Exposure Ratings for Products (cosmetics sector)

Products Cosmetics	No.	N.P	Conc. Rating	Contact Rating	Release Potential Rating	Market Penetr.	Rating F	Rating I	Δ Rating F - I
[redacted]	34	SiO_2	1	1	1	4	9	7	2
Various cosmetics	96	SiO_2	1	1	1	N.S.	5	3	2
[redacted]	126	SiO_2	1	1	1	4	9	7	2
[redacted]	5	Lipid	2	1	1	4	11	8	3
[redacted]	14	AlO	2	1	1	4	11	8	3
[redacted]	16	AlO	2	1	1	4	10	8	2
[redacted]	33	Lipid	2	1	1	4	10	8	2
[redacted]	50	Lipid	2	1	1	4	10	8	2
[redacted]	51	AlO	2	1	1	4	10	8	2
Various cosmetics	97	lipid	2	1	1	3	9	7	2
Various cosmetics [redacted]	99	ZnO	2	1	1	3	7	7	0
[redacted]	8	N.S.	N.S.	1	1	N.S.	N.S.	N.S.	
[redacted]	33	C60	3	1	1	4	11	9	2
[redacted]	35	C60	3	1	1	4	11	9	2

Products Cosmetics	**No.**	**N.P**	**Conc. Rating**	**Contact Rating**	**Release Potential Rating**	**Market Penetr.**	**Rating F**	**Rating I**	Δ Rating F - I
[redacted]	58	N.S.	N.S.	1	1	N.S.	N.S.	N.S.	
[redacted]	61	N.S.	N.S.	1	1	N.S.	N.S.	N.S.	
Various cosmetics	98	C60	3	1	1	4	11	9	2
Various cosmetics [redacted]	102	Ceramid	unknown	1	1	4	11	(9)*	2
[redacted]	125	C60	3	1	1	4	11	9	2
Various cosmetics [redacted]	101	Lipid	2	1	1	4	10	8	2
[redacted]	11	Proteins	unknown	1	1	4	11	(9)*	2
Various cosmetics	100	Vitamin E	unknown	1	1	4	11	(9)*	2
[redacted]	**56**	**N.S.**	**unknown**	**unknown**	**unknown**	**N.S.**	**No Data**	-	

* Where the concentration is 'unknown', a rating has been computed on the basis of the using the score of 5 (assigned in Task 3 and 4) for the concentration element of the formula.

Filtration

Due to the lack of data regarding nanomaterial type and content within the filtration sector, a quantitative comparative assessment could not be achieved.

Table 6.17. Comparative Exposure Ratings for Products (filtration devices sector)

Products Filtration Devices	No.	N.P	Conc. Rating	Contact Rating	Release Potential Rating	Market Penetr.	Rating F	Rating I	Δ Rating F - I
[redacted]	6	N.S.	N.S.	2	3	N.S.	-	-	
[redacted]	7	N.S.	N.S.	2	3	N.S.	-	-	
Various Air conditioning units	**75**	**N.S.**	**N.S.**	**3**	**3**	**N.S.**	-	-	

Home and Garden

The estimated exposure risk to consumers from dermal contact with washing machines containing nano-silver is considered to be greater than the exposure risk anticipated through drinking water.

The high exposure ranking, as detailed in Table 6.18, is derived from the relatively high concentration of nanomaterial within the product, the high level of contact between the consumer and the product and the ease of which the nanomaterial can come into direct contact with the consumer.

Table 6.18. Comparative Exposure Ratings for Products (home & garden sector)

Products Home and Garden	No.	N.P	Conc. Rating	Contact Rating	Release Potential Rating	Market Penetr.	Rating F	Rating I	Δ Rating F - I
Various Washing Machines	122	Ag	1	1	1	N.S.	5	3	2
[redacted]	123	Ag	1	1	1	4	9	7	2
[redacted]	17	N.S.	N.S.	3	3	N.S.	No Data	-	
Various Vacuum Cleaners	121	N.S.	N.S.	3	3	N.S.	No Data	-	
[redacted]	59	N.S.	N.S.	Unclear	Unclear	N.S.	No Data	-	
Various Refrigerators	105	N.S.	N.S.	Unclear	Unclear	N.S.	No Data	-	
Various Refrigerators	106	N.S.	N.S.	Unclear	Unclear	N.S.	No Data	-	
Various Refrigerators	**107**	**N.S.**	**N.S.**	**Unclear**	**Unclear**	**N.S.**	**No Data**	**-**	

Personal Care

The estimated exposure risk to consumers from dermal contact with personal care products is considered to be greater than the exposure risk anticipated through drinking water.

The high exposure ranking of these types of products, as detailed in Table 6.19, is derived from the relatively high concentration of nanomaterial within the product, the high level of contact between the consumer and the product and the ease of which the nanomaterial can come into direct contact with the consumer.

Table 6.19. Comparative Exposure Ratings for Products (personal care sector)

Products Personal Care	No.	N.P	Conc. Rating	Contact Rating	Release Potential Rating	Market Penetr.	Rating F	Rating I	Δ Rating F - I
[redacted]	68	Calcium	1	1	1	3	7	6	1
[redacted]	12	SiO_2	1	1	1	3	7	6	1
[redacted]	39	keratin	2	1	1	1	7	5	2
[redacted]	39	keratin	2	1	1	1	7	5	2
[redacted]	39	keratin	2	1	1	1	7	5	2
[redacted]	39	keratin	2	1	1	1	7	5	2
[redacted]	39	keratin	2	1	1	1	7	5	2
[redacted]	39	keratin	2	1	1	1	7	5	2
[redacted]	32	N.S.	N.S.	1	1	N.S.	No Data	-	
[redacted]	40	N.S	N.S	1	2	N.S.	No Data	-	
[redacted]	4	N.S.	N.S.	High	Unclear	N.S.	No Data	-	
[redacted]	37	N.S.	N.S.	High	Unclear	N.S.	No Data	-	
[redacted]	26	N.S.	N.S.	High	Unclear	N.S.	-	-	
[redacted]	54	TiO_2 (Mn)	1	1	1	N.S.	No Data	3	
Various Sunscreens	108	TiO_2	1	1	1	1	6	4	2

Products Personal Care	No.	N.P	Conc. Rating	Contact Rating	Release Potential Rating	Market Penetr.	Rating F	Rating I	Δ Rating F - I
Various Sunscreens	109	TiO_2	1	1	1	1	6	4	2
Various Sunscreens	110	ZnO	1	1	1	1	6	4	2
Various Sunscreens	111	N.S.	1	1	1	N.S.	No Data	3	
Various Sunscreens	112	N.S.	1	1	1	N.S.	No Data	3	
Various Sunscreens	113	N.S.	1	1	1	N.S.	No Data	3	
Various Sunscreens	114	TiO_2	1	1	1	1	6	4	2
Various Sunscreens	115	ZnO	1	1	1	2	5	7	2
Various Sunscreens	117	ZnO	1	1	1	2	7	5	2
Various Sunscreens	119	ZnO	1	1	1	2	7	5	2
Various Sunscreens	120	TiO2	1	1	1	N.S.	No Data	3	
[redacted]	67	TiO_2 (Mn)	2	1	1	1	7	5	2
Various Sunscreens	116	ZnO	2	1	1	2	8	6	2
Various Sunscreens	118	ZnO	2	1	1	2	8	6	2
Various Sunscreens	120	C60	3	1	1	N.S.	No Data	5	
[redacted]	53	N.S.	N.S.	1	1	N.S.	No Data	-	
[redacted]	**66**	**CoEnzyme**	**1**	**1**	**1**	**4**	**10**	**7**	3

Sporting Goods

Exposure (dermal, inhalation, ingestion) to nanomaterials in sporting goods would be anticipated to be very low as the nanomaterials would be expected to be bound within a matrix within the product. Despite dermal contact being high with the products, the nanomaterials would not be anticipated to migrate towards to outer surface and be released from the product; the release potential has subsequently been scored as 3 within Table 6.20. However, there is insufficient data from Chapter 3 & 5 for a comparison to be made.

Table 6.20. Comparative Exposure Ratings for Products (sporting goods sector)

Products Sporting Goods	No.	N.P	Conc. Rating	Contact Rating	Release Potential Rating	Market Penetr.	Rating F	Rating I	Δ Rating F - I
[redacted]	10	N.S.	N.S.	1	**3**	N.S.	No Data	-	
[redacted]	20	N.S.	N.S.	1	**3**	N.S.	No Data	-	
[redacted]	23	N.S.	N.S.	1	**3**	N.S.	No Data	-	
[redacted]	24	N.S.	N.S.	1	**3**	N.S.	No Data	-	
Golf clubs	27	N.S.	N.S.	1	**3**	N.S.	No Data	-	
[redacted]	31	N.S.	N.S.	1	**3**	N.S.	No Data	-	
[redacted]	43	N.S.	N.S.	1	**3**	N.S.	No Data	-	
[redacted]	44	N.S.	N.S.	1	**3**	N.S.	No Data	-	
[redacted]	45	N.S.	N.S.	1	**3**	N.S.	No Data	-	

Products Sporting Goods	No.	N.P	Conc. Rating	Contact Rating	Release Potential Rating	Market Penetr.	Rating F	Rating I	Δ Rating F - I
[redacted]	47	N.S.	N.S.	1	**3**	N.S.	No Data	-	
[redacted]	48	N.S.	N.S.	1	**3**	N.S.	No Data	-	
[redacted]	49	N.S.	N.S.	1	**3**	N.S.	No Data	-	
[redacted]	52	N.S.	N.S.	1	**3**	N.S.	No Data	-	
[redacted]	57	N.S.	N.S.	1	**3**	N.S.	No Data	-	
Tennis Rackets	70	N.S.	N.S.	1	**3**	N.S.	No Data	-	
Tennis Racket	71	N.S.	N.S.	1	**3**	N.S.	No Data	-	
[redacted]	73	N.S.		1	**3**	N.S.	No Data	-	
various cycle components	103	N.S.	N.S.	1	**3**	N.S.	No Data	-	
[redacted]	124	N.S	N.S	1	**3**	N.S.	No Data	-	
Bath and Sports Towels	9	Ag	4	1	2	N.S.	No Data	7	
[redacted]	18	N.S.	N.S.	1	**3**	N.S.	No Data	-	
Different bicycle parts [redacted]	**19**	**N.S.**	**N.S.**	**1**	**3**	**N.S.**	**No Data**	**-**	

6.4 Summary

A collation of relative risk ratings is provided where a numerical comparison of the difference between the risk ratings of exposure via drinking water and non-drinking water source has been possible. Those having a higher relative rating are provided first. Products which had insufficient data as part of the information given in Chapter 3 & 5, or for which insufficient data was available for Chapter 6, are not included in the summary collation of relative risk ratings (also see Appendix 8).

It should be noted that this is a product by product analysis and does not reflect human exposure at an individual level. An individual's exposure via drinking water to any of the nanoparticles identified may be lower or higher than exposure to the same nanoparticles from non-drinking water sources, subject to the individual's use of nanoparticle containing products. For example titanium dioxide exposure from paints and coating uses indirectly via drinking water may be a small fraction of direct exposure to titanium dioxide from sunscreen use.

Exposure risk higher from drinking water

The products in Table 6.21 have been qualitatively assessed as having a higher exposure to nanoparticles from drinking water than from dermal, inhalation or oral routes. Products which had insufficient data as part of the list received from Chapters 3 & 5 have been removed from this summary.

Products which are expected to have a higher exposure risk to nanoparticles in drinking water, containing nanomaterials suspended in solids or liquids, fall into two product sectors: clothing, and paints and coatings.

However, the main exposure route to nanoparticles in textiles is not clear from the literature. Experts' opinion (Wijnhoven et al. 2009) suggested dermal exposure as the expected exposure route where there is a large surface area of contact, intensive contact and where matrix bound nanoparticles may have the potential to be released by sweating. In contrast, the BfR (Federal Institute for Risk Assessment – Information No. 018/2007 (2007)) has stated that uptake of particles through the skin (dermal exposure) is assumed not to happen due to the size of the abraded particles. Moreover, despite a high frequency of use and high dermal contact for nano-containing clothes, Chaudhry et al. (2009) consider that the bound nature of nanoparticles would result in a very low exposure risk.

Conversely for the paints and coating products, the nanomaterial is unbound and suspended in liquid which would score the products highly with regards to potential release. Direct consumer exposure to paints and coatings however is considered to be low and subsequently the overall exposure risk is low.

Table 6.21 Products Expected to have Higher Exposure Risk from Drinking Water

Products	**No.**	**N.P**	**Sector**	**Nanomaterial Location**	**Rating F**	**Rating I**	Δ Rating F - I
Business & Sports Socks	13	Ag	Clothing	suspended in solids	10	11	-1
[redacted]	63	Ag	Clothing	suspended in solids	6	7	-1
[redacted]	64	Ag	Clothing	suspended in solids	6	7	-1
[redacted]	65	Ag	Clothing	suspended in solids	10	11	-1
[redacted]	1	Ag	Clothing	suspended in solids	11	12	-1
Various Clothing Lines	94	Al	Clothing	suspended in solid	11	12	-1
A range of surface coatings and paints	3	Carbon	Paints & Coatings	suspended in liquid	8	9	-1
[redacted]	55	TiO_2	Paints & Coatings	suspended in liquid	9	12	-3
[redacted]	29	Fe_2O_3	Paints & Coatings	suspended in liquid	8	9	-1
[redacted]	28	TiO_2	Paints & Coatings	suspended in liquid	9	11	-2
[redacted]	**2**	**Ag**	**Cleaning**	**surface bound**	**11**	**12**	-1

Exposure risk commensurate with drinking water

The products in Table 6.22 have been qualitatively assessed as having a similar exposure to nanoparticles from drinking water than from dermal, inhalation or oral routes. Products which had insufficient data as part of the list received from Chapters 3 & 5 have been removed from this summary.

Table 6.22. Products Expected to have Commensurate Exposure Risk

Products Automot.	**No.**	**N.P**	**Sector**	**Nanomaterial Location**	**Release Potential Rating**	**Rating F**	**Rating I**	Δ Rating F - I
[redacted]	22	CeO	Auto	suspended in liquid	3	10	10	0
Various Clothing Lines	92	SiO_2	Clothing	surface bound	3	10	10	0
Various Clothing Lines	93	SiO_2	Clothing	surface bound	3	10	10	0
Various Clothing Lines	95	SiO_2	Clothing	Surface bound	3	10	10	0
[redacted]	15	Ceramic	Paints and Coatings	suspended in liquid	1	9	9	0
Various cosmetics [redacted]	**99**	**ZnO**	**Cosmetics**	**suspended in liquid**	**1**	**7**	**7**	0

Exposure risk lower from drinking water

The products in Table 6.23 have been qualitatively assessed as having a lower exposure to nanoparticles from drinking water than from dermal, inhalation or oral routes. Products which had insufficient data as part of the list received from Chapters 3 & 5 have been removed from this summary.

The majority of products investigated resulted in a scoring which anticipated nanoparticle exposure risk to consumers as being greater for the dermal, inhalation or oral routes compared to exposure risk from drinking water.

The products come from a range of sectors although cosmetics and personal care were seen to be dominant. Most products were seen to be liquid in nature and were designed to come into direct (dermal) contact with the consumer e.g. application of sunscreen, cosmetics, cleaning waxes etc. A nanoparticle in such a system is unrestricted in its movement within the product and subsequently direct dermal contact is highly likely.

Table 6.23. Products Expected to have Lower Exposure Risk from Drinking Water

Products	**No.**	**N.P**	**Sector**	**Nanomaterial Location**	**Rating F**	**Rating I**	Δ Rating F - I
[redacted]	21	SiO_2	Auto	suspended in liquid	10	8	2
		ZnO	Auto	suspended in liquid	10	8	2
[redacted]	25	ZnO	Auto	suspended in liquid	6	4	2
[redacted]	38	Silazane	Auto	suspended in liquid	10	8	2
		SiO_2	Auto	suspended in liquid	10	8	2
		ZnO	Auto	suspended in liquid	10	8	2
[redacted]	41	SiO_2	Auto	suspended in liquid	8	6	2
		ZnO	Auto	suspended in liquid	8	6	2
[redacted]	42	SiO_2	Auto	suspended in liquid	10	8	2
		ZnO	Auto	suspended in liquid	10	8	2
[redacted]	72	SiO_2	Auto	suspended in liquid	8	6	2
		ZnO	Auto	suspended in liquid	8	6	2
[redacted]	60	TiO_2	Cleaning	surface bound	9	8	1

Products	No.	N.P	Sector	Nanomaterial Location	Rating F	Rating I	Δ Rating F - I
[redacted]	69	SiO_2	Paints & Coatings	suspended in liquid	10	8	2
[redacted]	34	SiO_2	Cosmetics	suspended in liquid	11	9	2
Various cosmetics	96	SiO_2	Cosmetics	suspended in liquid	5	3	2
[redacted]	126	SiO_2	Cosmetics	suspended in liquid	9	7	2
[redacted]	5	Lipid	Cosmetics	suspended in liquid	11	8	3
[redacted]	14	AlO	Cosmetics	suspended in liquid	11	8	3
[redacted]	16	AlO	Cosmetics	suspended in liquid	10	8	2
[redacted]	33	Lipid	Cosmetics	suspended in liquid	10	8	2
[redacted]	50	Lipid	Cosmetics	suspended in liquid	10	8	2
[redacted]	51	AlO	Cosmetics	suspended in liquid	10	8	2
Various cosmetics	97	lipid	Cosmetics	suspended in liquid	9	7	2
[redacted]	33	C60	Cosmetics	suspended in liquid	11	9	2
[redacted]	35	C60	Cosmetics	suspended in liquid	11	9	2
Various cosmetics	98	C60	Cosmetics	suspended in liquid	11	9	2
[redacted]	102	Ceramid	Cosmetics	suspended in liquid	11	(9)*	2

Products	No.	N.P	Sector	Nanomaterial Location	Rating F	Rating I	Δ Rating F - I
[redacted]	125	C60	Cosmetics	suspended in liquid	11	9	2
Various cosmetics [redacted]	101	Lipid	Cosmetics	suspended in liquid	10	8	2
Various Washing Machines	122	Ag	Home and Garden	surface bound	5	3	2
[redacted]	123	Ag	Home and Garden	surface bound	9	7	2
[redacted]	68	Calcium	Personal Care	suspended in liquid	7	6	1
[redacted]	12	SiO_2	Personal Care	suspended in liquid	7	6	1
Various Sunscreens	108	TiO_2	Personal Care	suspended in liquid	6	4	2
Various Sunscreens	109	TiO_2	Personal Care	suspended in liquid	6	4	2
Various Sunscreens	110	ZnO	Personal Care	suspended in liquid	7	5	2
Various Sunscreens	114	TiO_2	Personal Care	suspended in liquid	6	4	2
Various Sunscreens	115	ZnO	Personal Care	suspended in liquid	7	5	2
Various Sunscreens	117	ZnO	Personal Care	suspended in liquid	7	5	2

Products	**No.**	**N.P**	**Sector**	**Nanomaterial Location**	**Rating F**	**Rating I**	Δ Rating F - I
Various Sunscreens	119	ZnO	Personal Care	suspended in liquid	7	5	2
[redacted]	67	TiO_2 (Mn)	Personal Care	suspended in liquid	7	5	2
Various Sunscreens	116	ZnO	Personal Care	suspended in liquid	8	6	2
Various Sunscreens	118	ZnO	Personal Care	suspended in liquid	8	6	2
[redacted]	66	CoEnzyme	Personal Care	suspended in liquid	10	7	3
[redacted]	39	keratin	Personal Care	suspended in liquid	7	5	2
[redacted]	39	keratin	Personal Care	suspended in liquid	7	5	2
[redacted]	39	keratin	Personal Care	suspended in liquid	7	5	2
[redacted]	39	keratin	Personal Care	suspended in liquid	7	5	2
[redacted]	39	keratin	Personal Care	suspended in liquid	7	5	2
[redacted]	**39**	**keratin**	**Personal Care**	**suspended in liquid**	7	5	2

* Where the concentration is 'unknown', a rating has been computed on the basis of the using the score of 5 (assigned in Chapter 3 to 5) for the concentration element of the formula.

7. Discussion and Recommendations

Nanotechnology is a fast growing market and consumer products containing engineered nanomaterials can readily be bought on the UK market. Therefore, it is inevitable that consumers will be exposed to nanoparticles *via* direct product usage or via environmental pathways. There are currently major uncertainties concerning the risks of nanoparticles to human health, particularly from environmental exposure pathways. The aim of this study was therefore to investigate the potential for man-made nanoparticles to contaminate drinking water supplies and to compare the significance of the drinking water route of exposure with other routes of exposure. As a first step, those ENM containing products on the UK market were identified that are likely to result in ENP releases to source waters. ENP concentrations in raw water and treated drinking waters were then estimated. Due to a lack of data on ENP usage, release and fate, a qualitative approach was then used to identify whether or not drinking water is likely to be a significant route of exposure for humans compared to other exposure routes on a product by product basis.

Products containing nanomaterials and available on the UK market have been identified in Chapter 3. However, this may not be a true reflection of the nanoparticle-containing products that are actually in use due to the fact that:

1) many nano-containing products can be bought via the internet worldwide;
2) products do not have to be labelled when containing nanomaterials;
3) even if stated that a product contains nanomaterials, this might actually not be the case;
4) new products are frequently launched, but are often withdrawn from the market again soon after.

Additionally, due to a lack of published data, in most cases, it was not possible to estimate the UK market penetration for these products. Moreover, whilst some data are available on the concentrations of ENPs in selected products, for some products this is totally lacking.

The potential of nanomaterials to be released into the aquatic environment, but also the risk of direct exposure of nanomaterials to consumers is highly dependent on the location of the nanomaterial within a product. Nanomaterials suspended in liquids (e.g. sunscreens) or located on the product surface (e.g. coatings, clothing) pose a higher risk, than products in which nanomaterials are embedded in a solid substance (e.g. tennis rackets). In Chapter 4 the categorisation framework developed by Hansen et al. (2008) was applied to the identified products to classify their potential risk of exposure and release to the environment. For some products the location of the ENM within the product could not be assessed due to a lack of information provided by the manufacturers.

The main pathway by which ENPs will reach drinking waters is through discharges to the aquatic environment. Once released into the aquatic environment, nanomaterials might undergo substantial changes, e.g. aggregation or dissolution depending on particle characteristics (e.g. type, size, surface properties and, for magnetic metal particles, the intrinsic magnetic moment) and environmental conditions (e.g. pH, ionic strength and dissolved organic carbon content). The behaviour of nanoparticles in the environment is highly complex and due to sophisticated particle engineering (e.g. surface functionalisation), a generalisation of particle behaviour, transport and fate in the environment is not possible. To date little is known about nanoparticle behaviour and fate in aquatic systems. In the absence of scientific data, however, modelling approaches can be used to estimate potential concentrations of ENPs in wastewater, surface waters and drinking water.

Due to the lack of knowledge on ENP fate and behaviour in the environment and uncertainty in the use data, we have used a pragmatic approach to 1) identify the types of ENPs that could contaminate drinking water supplies; and 2) attempted to assess the significance of the drinking water exposure route compared to other routes of exposure in terms of potential risks to consumers.

Using the information in Chapter 3 and 4, the modelling framework was applied to estimate the likely concentrations of ENPs in the UK raw and treated drinking waters. For the 97% nanoparticle removal scenario in WWTPs, concentrations of ENPs were found to be in the low ug/L range in raw water and very much lower in treated water (Table 7.1). These exposure concentrations assume complete release to the environment, do not consider removal in the environment (e.g. due to sedimentation) and so are probably highly conservative although it is also important to recognise that for many NPs lower removal efficiencies in WWTPs will apply (concentration estimates for 0% removal efficiencies as the most conservative approach is also provided in Chapter 5).

Table 7.1. Summary of exposure data for selected ENPs in the UK environment (assuming 97% ENP removal in WWTPs)

type	removal WWTP	WTP (influent) ug/L	WTP (conventional) ug/L	WTP (membrane) ug/L	WTP (filtration) ug/L
Titanium oxide	97%	4.91E+00	4.91E-02	4.91E-04	1.55E-01
Zinc oxide	97%	1.91E+00	1.91E-02	1.91E-04	6.03E-02
Silica	97%	1.20E+00	1.20E-02	1.20E-04	3.79E-02
Ceramic	97%	1.10E+00	1.10E-02	1.10E-04	3.48E-02
Carbon & C60	97%	6.62E-01	6.62E-03	6.62E-05	2.09E-02
Carbon	97%	6.60E-01	6.60E-03	6.60E-05	2.09E-02
Iron oxide	97%	6.60E-01	6.60E-03	6.60E-05	2.09E-02
Silver	97%	3.21E-01	3.21E-03	3.21E-05	1.02E-02
Keratin	97%	2.48E-01	2.48E-03	2.48E-05	7.84E-03
Ca peroxide	97%	2.15E-01	2.15E-03	2.15E-05	6.80E-03
Encapsulates	97%	5.92E-02	5.92E-04	5.92E-06	1.87E-03
Aluminium & aluminium oxide	97%	3.87E-03	3.87E-05	3.87E-07	1.22E-04
Silazane	97%	3.00E-03	3.00E-05	3.00E-07	9.49E-05
C60	97%	1.73E-03	1.73E-05	1.73E-07	5.47E-05
Cerium oxide	97%	1.40E-06	1.40E-08	1.40E-10	4.43E-08

In Chapter 6, a simple scoring system was used to assess the likelihood of exposure via drinking water compared to other routes of exposure. Products most likely to result in higher exposure via drinking water are shown in Table 7.2 and included clothing, paints and coatings and cleaning. These products contain either metal ENPs (Ag), metal oxides (TiO_2, Fe_2O_3, Al_2O_3) or carbon-based materials.

Table 7.2 Products expected to have higher exposure risk from drinking water

Products	No.	NP type	Sector	Nanomaterial location in product
Socks	13	Ag	Clothing	suspended in solids
Socks	63	Ag	Clothing	suspended in solids
Socks	64	Ag	Clothing	suspended in solids
Socks	65	Ag	Clothing	suspended in solids
Sheets	1	Ag	Clothing	suspended in solids
Clothing	94	Al	Clothing	suspended in solid
Surface coatings and paints	3	Carbon	Paints & Coatings	suspended in liquid
Self Cleaning Glass	55	TiO_2	Paints & Coatings	suspended in liquid
Water-based paints	29	Fe_2O_3	Paints & Coatings	suspended in liquid
Tiles	28	TiO_2	Paints & Coatings	suspended in liquid
Wipes	2	Ag	Cleaning	surface bound

Although predicted concentrations of these materials in UK drinking water are low, any future work on risks of ENPs to drinking waters should probably focus on these ENP types (Table 7.2).

7.1. Conclusions

It is inevitable that during their use ENPs will be released to the environment. Some of these particles may then reach drinking water supplies. This study was therefore performed to identify the types of ENPs that have the greatest potential to contaminate drinking water supplies and to assess the potential significance of drinking water in terms of human exposure to ENPs. A range of metal, metal oxide and organic-based ENPs were identified that have the potential to contaminate drinking waters. Predicted concentrations in drinking waters were in the low to sub-$\mu g\ l^{-1}$ range. For the majority of product types, human exposure via drinking water is predicted to be less important than exposure via other routes. The exceptions were some clothing materials, paints and coatings and cleaning products. The particles contained in these products include Ag, Al/Al_2O_3, TiO_2, Fe_2O_3 and carbon-based materials. Although estimated concentrations in treated drinking water are very low, any future work on risks of ENPs to drinking waters should probably focus on these materials.

It should be noted that this is a product by product analysis and does not reflect human exposure at an individual level. An individual's exposure via drinking water to any of the nanoparticles identified may be lower or higher than exposure to the same nanoparticles from non-drinking water sources, subject to the individual's use of nanoparticle containing products. For example titanium dioxide exposure from paints and coating uses indirectly via drinking water may be a small fraction of direct exposure to titanium dioxide from sunscreen use.

7.2. Recommendations for future work

It is clear from this study that there are significant gaps in our current knowledge regarding the use, environmental fate and exposure of ENPs in the UK environment. This makes it very difficult to assess the actual risks of ENPs to drinking water supplies. We would therefore advocate that work in the future focuses on the following areas:

1. The development and maintenance of an inventory of which products in use in the UK containing ENMs, the concentrations of the ENPs within the products and the specific characteristics of ENPs used in these product (non-functionalised vs. functionalised, size, shape etc.).
2. The development of emission scenarios for ENPs at different stages of a product life cycle. In this project we have assumed that inputs from the manufacturing process and disposal are minimal compared to inputs during use. Moreover we have only been able to develop usage scenarios for selected product types.
3. Production of data on the amounts of ENM-products sold in the UK.
4. Studies to explore the fate and behaviour of ENPs in a range of environmental systems (wastewater treatment, surface waters, drinking water treatment).
5. Based on the information obtained from the types of studies described above, models for more accurately predicting concentrations of ENPs in natural systems should be developed. These models should not only estimate exposure concentrations but also the characteristics (size, shape, surface

properties) ENPs are likely to adopt in the natural environment and in drinking waters. It is possible that existing environmental exposure models could be adapted using models from other disciplines (e.g. colloid science) to achieve this.

6. The development and validation of analytical methods for measuring ENPs in drinking waters. Ultimately, these approaches should be used for environmental monitoring purposes and the validation of exposure models.
7. Assessment of the potential risks of ENPs in drinking water to human health.

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Appendices

Appendix 1 – List of products containing ENMs available on the UK market including companies, type of ENM and estimated worldwide product use

Product ID	No.	Product	Company	Source	ENP type	Product use in t (Wijnhoven et al. 2009)
1	1	[redacted]	[redacted]	[redacted]	Ag	>10,000 (coatings, paints)
2	2	[redacted]	[redacted]	[redacted]	Ag	100-1,000
2	3	[redacted]	[redacted]	[redacted]	TiO2	100-1,000
3	4	[redacted]	[redacted]	[redacted]	C	unknown
4	5	[redacted]	[redacted]	[redacted]	Ag	1,000-10,000
4	6	[redacted]	[redacted]	[redacted]	C	1,000-10,000
5	7	[redacted]	[redacted]	[redacted]	lipid encapsulates	1,000-10,000
6	8	[redacted]	[redacted]	[redacted]	Ag	10-100
6	9	[redacted]	[redacted]	[redacted]	C	10-100
6	10	[redacted]	[redacted]	[redacted]	Cu	10-100
6	11	[redacted]	[redacted]	[redacted]	ZnO	10-100
7	12	[redacted]	[redacted]	[redacted]	Ag	10-100
7	13	[redacted]	[redacted]	[redacted]	C	10-100
8	14	[redacted]	[redacted]	[redacted]	TiO2	1,000-10,000
9	15	[redacted]	[redacted]	[redacted]	Ag	10-100
10	16	[redacted]	[redacted]	[redacted]	n/a	10-100
11	17	[redacted]	[redacted]	[redacted]	proteins	1,000-10,000
12	18	[redacted]	[redacted]	[redacted]	SiO2	1,000-10,000
13	19	[redacted]	[redacted]	[redacted]	Ag	>10,000 (coatings, paints)
14	20	[redacted]	[redacted]	[redacted]	AlO	1,000-10,000
15	21	[redacted]	[redacted]	[redacted]	ceramic	>10,000
16	22	[redacted]	[redacted]	[redacted]	AlO	1,000-10,000
17	23	[redacted]	[redacted]	[redacted]	Ag	100-1,000 (cleaning)

Product ID	No.	Product	Company	Source	ENP type	Product use in t (Wijnhoven et al. 2009)
18	24	[redacted]	[redacted]	[redacted]	C	10-100
19	25	[redacted]	[redacted]	[redacted]	CNT	10-100
20	26	[redacted]	[redacted]	[redacted]	clay	10-100
21	27	[redacted]	[redacted]	[redacted]	SiO2	100-1,000
21	28	[redacted]	[redacted]	[redacted]	ZnO	100-1,000
22	29	[redacted]	[redacted]	[redacted]	CeO	unknown
23	30	[redacted]	[redacted]	[redacted]	n/a	10-100
24	31	[redacted]	[redacted]	[redacted]	CNT	10-100
25	32	[redacted]	[redacted]	[redacted]	ZnO	100-1,000
26	33	[redacted]	[redacted]	[redacted]	n/a	1,000-10,000
27	34	[redacted]	[redacted]	[redacted]	C60	10-100
27	35	[redacted]	[redacted]	[redacted]	Ti	10-100
28	36	[redacted]	[redacted]	[redacted]	TiO2	>10,000
29	37	[redacted]	[redacted]	[redacted]	Fe2O3	>10,000
30	38	[redacted]	[redacted]	[redacted]	n/a	>10,000
31	39	[redacted]	[redacted]	[redacted]	C	10-100
31	40	[redacted]	[redacted]	[redacted]	Ti	10-100
32	41	[redacted]	[redacted]	[redacted]	SiO2	1,000-10,000
32	42	[redacted]	[redacted]	[redacted]	Zr	1,000-10,000
33	43	[redacted]	[redacted]	[redacted]	C60	1,000-10,000
33	44	[redacted]	[redacted]	[redacted]	lipid encapsulates	1,000-10,000
34	45	[redacted]	[redacted]	[redacted]	SiO2	1,000-10,000
35	46	[redacted]	[redacted]	[redacted]	C60	1,000-10,000
36	47	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
37	48	[redacted]	[redacted]	[redacted]	n/a	1,000-10,000
38	49	[redacted]	[redacted]	[redacted]	silazane	100-1,000
38	50	[redacted]	[redacted]	[redacted]	SiO2	100-1,000
38	51	[redacted]	[redacted]	[redacted]	ZnO	100-1,000

Product ID	No.	Product	Company	Source	ENP type	Product use in t (Wijnhoven et al. 2009)
39	52	[redacted]	[redacted]	[redacted]	keratin fibres	1,000-10,000
39	53	[redacted]	[redacted]	[redacted]	keratin fibres	1,000-10,000
39	54	[redacted]	[redacted]	[redacted]	keratin fibres	1,000-10,000
39	55	[redacted]	[redacted]	[redacted]	keratin fibres	1,000-10,000
39	56	[redacted]	[redacted]	[redacted]	keratin fibres	1,000-10,000
39	57	[redacted]	[redacted]	[redacted]	keratin fibres	1,000-10,000
40	58	[redacted]	[redacted]	[redacted]	n/a	1,000-10,000
41	59	[redacted]	[redacted]	[redacted]	SiO2	100-1,000
41	60	[redacted]	[redacted]	[redacted]	ZnO	100-1,000
42	61	[redacted]	[redacted]	[redacted]	SiO2	100-1,000
42	62	[redacted]	[redacted]	[redacted]	ZnO	100-1,000
43	63	[redacted]	[redacted]	[redacted]	CNT	10-100
44	64	[redacted]	[redacted]	[redacted]	CNT	10-100
45	65	[redacted]	[redacted]	[redacted]	CNT	10-100
46	66	[redacted]	[redacted]	[redacted]	n/a	100-1,000
47	67	[redacted]	[redacted]	[redacted]	CNT	10-100
48	68	[redacted]	[redacted]	[redacted]	CNT	10-100
49	69	[redacted]	[redacted]	[redacted]	CNT	10-100
50	70	[redacted]	[redacted]	[redacted]	lipid encapsulates	1,000-10,000
51	71	[redacted]	[redacted]	[redacted]	AlO	1,000-10,000
52	72	[redacted]	[redacted]	[redacted]	CNT	10-100
53	73	[redacted]	[redacted]	[redacted]	n/a	1,000-10,000
54	74	[redacted]	[redacted]	[redacted]	TiO2 (Mn doped)	1,000-10,000
55	75	[redacted]	[redacted]	[redacted]	TiO2	unknown
56	76	[redacted]	[redacted]	[redacted]	TiO2	1,000-10,000
57	77	[redacted]	[redacted]	[redacted]	CNT	10-100
58	78	[redacted]	[redacted]	[redacted]	n/a	1,000-10,000
59	79	[redacted]	[redacted]	[redacted]	Ag	>10,000 (food packaging)

Product ID	No.	Product	Company	Source	ENP type	Product use in t (Wijnhoven et al. 2009)
60	80	[redacted]	[redacted]	[redacted]	TiO2	100-1,000
61	81	[redacted]	[redacted]	[redacted]	n/a	1,000-10,000
62	82	[redacted]	[redacted]	[redacted]	n/a	unknown
63	83	[redacted]	[redacted]	[redacted]	Ag	>10,000 (coatings, paints)
64	84	[redacted]	[redacted]	[redacted]	Ag	>10,000 (coatings, paints)
65	85	[redacted]	[redacted]	[redacted]	Ag	>10,000 (coatings, paints)
66	86	[redacted]	[redacted]	[redacted]	micelles	unknown
67	87	[redacted]	[redacted]	[redacted]	TiO2 (Mn doped)	1,000-10,000
68	88	[redacted]	[redacted]	[redacted]	Ca peroxide	1,000-10,000
69	89	[redacted]	[redacted]	[redacted]	SiO2	unknown
70	90	[redacted]	[redacted]	[redacted]	CNT	10-100
71	91	[redacted]	[redacted]	[redacted]	CNT	10-100
72	92	[redacted]	[redacted]	[redacted]	SiO2	100-1,000
72	93	[redacted]	[redacted]	[redacted]	ZnO	100-1,000
73	94	[redacted]	[redacted]	[redacted]	clay	10-100
74	95	[redacted]	[redacted]	[redacted]	ceramic	unknown
75	96	[redacted]	[redacted]	[redacted]	Ag	10-100
76	97	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
77	98	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
78	99	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
79	100	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
80	101	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
81	102	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
82	103	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
83	104	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
84	105	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
85	106	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
86	107	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)

Product ID	No.	Product	Company	Source	ENP type	Product use in t (Wijnhoven et al. 2009)
87	108	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
88	109	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
89	110	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
90	111	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
91	112	[redacted]	[redacted]	[redacted]	n/a	>10,000 (coatings, paints)
92	113	[redacted]	[redacted]	[redacted]	SiO2	>10,000 (coatings, paints)
93	114	[redacted]	[redacted]	[redacted]	SiO2	>10,000 (coatings, paints)
94	115	[redacted]	[redacted]	[redacted]	Al	>10,000 (coatings, paints)
95	116	[redacted]	[redacted]	[redacted]	SiO2	>10,000 (coatings, paints)
96	117	[redacted]	[redacted]	[redacted]	SiO2	1,000-10,000
97	118	[redacted]	[redacted]	[redacted]	lipid encapsulates	1,000-10,000
98	119	[redacted]	[redacted]	[redacted]	C60 (fulleromes)	1,000-10,000
99	120	[redacted]	[redacted]	[redacted]	ZnO	1,000-10,000
100	121	[redacted]	[redacted]	[redacted]	Vitamin E nanocapsules	1,000-10,000
101	122	[redacted]	[redacted]	[redacted]	lipid encapsulates	1,000-10,000
102	123	[redacted]	[redacted]	[redacted]	ceramid nanocapsules	1,000-10,000
103	124	[redacted]	[redacted]	[redacted]	CNT	10-100
104	125	[redacted]	[redacted]	[redacted]	Ag	1,000-10,000
105	126	[redacted]	[redacted]	[redacted]	Ag	>10,000 (food packaging)
106	127	[redacted]	[redacted]	[redacted]	Ag	>10,000 (food packaging)
107	128	[redacted]	[redacted]	[redacted]	Ag	>10,000 (food packaging)
108	129	[redacted]	[redacted]	[redacted]	TiO2	1,000-10,000
109	130	[redacted]	[redacted]	[redacted]	TiO2	1,000-10,000
110	131	[redacted]	[redacted]	[redacted]	ZnO	1,000-10,000
111	132	[redacted]	[redacted]	[redacted]	n/a	1,000-10,000
112	133	[redacted]	[redacted]	[redacted]	n/a	1,000-10,000
113	134	[redacted]	[redacted]	[redacted]	n/a	1,000-10,000

Product ID	No.	Product	Company	Source	ENP type	Product use in t (Wijnhoven et al. 2009)
114	135	[redacted]	[redacted]	[redacted]	TiO2	1,000-10,000
115	136	[redacted]	[redacted]	[redacted]	ZnO	1,000-10,000
116	137	[redacted]	[redacted]	[redacted]	ZnO	1,000-10,000
117	138	[redacted]	[redacted]	[redacted]	ZnO	1,000-10,000
118	139	[redacted]	[redacted]	[redacted]	ZnO	1,000-10,000
119	140	[redacted]	[redacted]	[redacted]	ZnO	1,000-10,000
120	141	[redacted]	[redacted]	[redacted]	C60	1,000-10,000
120	142	[redacted]	[redacted]	[redacted]	TiO2	1,000-10,000
121	143	[redacted]	[redacted]	[redacted]	Ag	100-1,000 (cleaning)
122	144	[redacted]	[redacted]	[redacted]	Ag	100-1,000 (cleaning)
123	145	[redacted]	[redacted]	[redacted]	Ag	100-1,000 (cleaning)
124	146	[redacted]	[redacted]	[redacted]	n/a	10-100
125	147	[redacted]	[redacted]	[redacted]	C60	1,000-10,000
126	148	[redacted]	[redacted]	[redacted]	SiO2	1,000-10,000

Appendix 2 – Available or estimated ENP concentration and usage data as well as ENP size information for those products likely to reach the aquatic environment

No.	ENP type	Product type	Usage (g/pc/d)	Reference	Conc. (%)	Reference	Mean diameter	Notes	Reference
38	silazane	car polish	0.3	based on assumption	5	http://www.faqs.org/patents/app/20090025508	n/a		
21	SiO2	car polish	0.3	based on assumption	5	http://www.faqs.org/patents/app/20090025508	n/a		
38	SiO2	car polish	0.3	based on assumption	5	http://www.faqs.org/patents/app/20090025508	n/a		
41	SiO2	car polish	0.3	based on assumption	5	http://www.faqs.org/patents/app/20090025508	n/a		
42	SiO2	car polish	0.3	based on assumption	5	http://www.faqs.org/patents/app/20090025508	n/a		
72	SiO2	car polish	0.3	based on assumption	5	http://www.faqs.org/patents/app/20090025508	n/a	same product than 72, different source	[redacted]
21	ZnO	car polish	0.3	based on assumption	5	http://www.faqs.org/patents/app/20090025508	n/a		
25	ZnO	car polish	0.3	based on assumption	5	http://www.faqs.org/patents/app/20090025508	n/a	same product than 25, different source	
38	ZnO	car polish	0.3	based on assumption	5	http://www.faqs.org/patents/app/20090025508	n/a		
41	ZnO	car polish	0.3	based on assumption	5	http://www.faqs.org/patents/app/20090025508	n/a		
42	ZnO	car polish	0.3	based on assumption	5	http://www.faqs.org/patents/app/20090025508	n/a		
72	ZnO	car polish	0.3	based on assumption	5	http://www.faqs.org/patents/app/20090025508	n/a	same product than 72, different source	[redacted]
13	Ag	clothing	89	Benn & Westerhoff (2009)	0.27	Benn & Westerhoff (2009): pair of socks	25 nm		[redacted]
63	Ag	clothing	89	Benn & Westerhoff (2009)	0.27	Benn & Westerhoff (2009): pair of socks	150 nm		[redacted]
64	Ag	clothing	89	Benn & Westerhoff (2009)	0.27	Benn & Westerhoff (2009): pair of socks	151 nm		[redacted]
65	Ag	clothing	89	Benn & Westerhoff (2009)	0.27	Benn & Westerhoff (2009): pair of socks	152 nm		[redacted]
1	Ag	clothing	89	based on assumption	0.005	Lee et al. (2003)	25 nm		[redacted]

No.	ENP type	Product type	Usage (g/pc/d)	Reference	Conc. (%)	Reference	Mean diameter	Notes	Reference
9	Ag	clothing	89	based on assumption	0.005	Lee et al. (2003)	26 nm		[redacted]
94	Al	clothing	89	based on assumption	0.01	based on assumption	50 nm vapour layer on membrane	n/a	[redacted]
92	SiO2	clothing	89	based on assumption	4	Wu et al. (2009)	n/a		
93	SiO2	clothing	89	based on assumption	4	Wu et al. (2009)	n/a		
95	SiO2	clothing	89	based on assumption	4	Wu et al. (2009)	n/a		
2	Ag	coating	110	TGD (2003)	0.001-0.1	Boxall et al. (2007)	n/a		
15	ceramic	coating	110	based on assumption	10	Boxall et al 2007	n/a		
69	SiO2	coating	0.002	[redacted]	100	based on assumption	n/a		
2	TiO2	coating	110	TGD (2003)	5	Boxall et al 2007	n/a		
55	TiO2	coating	110	TGD (2003)	5	Boxall et al 2007	15 nm coating		[redacted]
60	TiO2	coating	110	TGD (2003)	5	Boxall et al 2007	n/a		
14	AlO	cosmetics	0.06	TGD (2003)	3	http://www.freepatentsonline.com/y2005/0074473.html	n/a		
16	AlO	cosmetics	0.8	TGD (2003)	3	http://www.freepatentsonline.com/y2005/0074473.html	<100 nm		[redacted]
51	AlO	cosmetics	0.8	TGD (2003)	3	http://www.freepatentsonline.com/y2005/0074473.html	<100 nm		[redacted]
35	C60	cosmetics	0.8	TGD (2003)	0.25	Boxall et al. (2007)	n/a		
125	C60	cosmetics	0.8	TGD (2003)	0.25	Boxall et al. (2007)	n/a		
33	C60	cosmetics	0.8	TGD (2003)	0.25	Boxall et al. (2007)	80-100 nm		http://www.springerlink.com/content/j06r4l5h9716w181/fulltext.pdf
98	C60 (fulleromes)	cosmetics	0.8	TGD (2003)	0.25	Boxall et al. (2007)	n/a		
102	ceramid nanocapsules	cosmetics	0.8	TGD (2003)	4	Mueller et al. (2006)	n/a		
5	lipid encapsulates	cosmetics	0.03	TGD (2003)	4	Mueller et al. (2006)	30-200 nm		[redacted]

No.	ENP type	Product type	Usage (g/pc/d)	Reference	Conc. (%)	Reference	Mean diameter	Notes	Reference
33	lipid encapsulates	cosmetics	0.8	TGD (2003)	4	Mueller et al. (2006)	80-100 nm		http://www.springerlink.com/content/j06r4l5h9716w181/fulltext.pdf
50	lipid encapsulates	cosmetics	0.8	TGD (2003)	4	Mueller et al. (2006)	500-700 nm		[redacted]
97	lipid encapsulates	cosmetics	0.8	TGD (2003)	4	Mueller et al. (2006)	500-700 nm		[redacted]
101	lipid encapsulates	cosmetics	0.8	TGD (2003)	4	Mueller et al. (2006)	30-200 nm		[redacted]
11	proteins	cosmetics	0.8	TGD (2003)	4	Mueller et al. (2006)	n/a		
34	SiO2	cosmetics	0.8	TGD (2003)	15	http://www.freepatentsonline.com/6335037.html	>10 nm		
96	SiO2	cosmetics	0.8	TGD (2003)	15	http://www.freepatentsonline.com/6335037.html	>10 nm		
126	SiO2	cosmetics	0.8	TGD (2003)	15	http://www.freepatentsonline.com/6335037.html	<1000 nm		
100	Vitamin E nanocapsules	cosmetics	0.8	TGD (2003)	4	Mueller et al. (2006)	82-144 nm		Liu and Park (2009)
99	ZnO	cosmetics	15	TGD (2003)	6	[redacted]	n/a		
22	CeO	fuel additive	0.007	based on assumption	0.001	Wakefield et al. (2008)	8-10 nm; 10-20nm	density: 7.13 g/ml	Wakefield et al. (2008); Sajith et al. (2009)
39	keratin fibres	hair treatment	0.2	TGD (2003)	10	http://www.freepatentsonline.com/4369037.html	n/a		
39	keratin fibres	hair treatment	0.2	TGD (2003)	10	http://www.freepatentsonline.com/4369037.html	n/a		
39	keratin fibres	hair treatment	0.2	TGD (2003)	10	http://www.freepatentsonline.com/4369037.html	n/a		
39	keratin fibres	hair treatment	0.2	TGD (2003)	10	http://www.freepatentsonline.com/4369037.html	n/a		
39	keratin fibres	hair treatment	0.2	TGD (2003)	10	http://www.freepatentsonline.com/4369037.html	n/a		
39	keratin fibres	hair treatment	0.2	TGD (2003)	10	http://www.freepatentsonline.com/4369037.html	n/a		
3	C	paint	33	Adams (2005)	10	[redacted]	n/a		
29	Fe2O3	paint	33	Adams (2005)	10	[redacted]	10-30nm	surface area: 35-40 m2/g	Doke and Khanna (2009)

No.	ENP type	Product type	Usage (g/pc/d)	Reference	Conc. (%)	Reference	Mean diameter	Notes	Reference
28	TiO2	paint	33	Adams (2005)	10	[redacted]	n/a		
120	C60	sunscreen	0.9	TGD (2003)	0.25	Boxall et al. (2007)	20-40 nm		[redacted]
108	TiO2	sunscreen	0.9	TGD (2003)	25	CosIng	20-40 nm		[redacted]
109	TiO2	sunscreen	0.9	TGD (2003)	25	CosIng	20-40 nm		[redacted]
114	TiO2	sunscreen	0.9	TGD (2003)	25	CosIng	20-40 nm		[redacted]
120	TiO2	sunscreen	0.9	TGD (2003)	25	CosIng	20-40 nm		[redacted]
54	TiO2 (Mn doped)	sunscreen	0.9	TGD (2003)	25	CosIng	50-60 nm		[redacted]
67	TiO2 (Mn doped)	sunscreen	0.9	TGD (2003)	5	[redacted]	70 nm	>97 % rutile	[redacted]
110	ZnO	sunscreen	0.9	TGD (2003)	25	CosIng	20-40 nm		[redacted]
115	ZnO	sunscreen	0.9	TGD (2003)	22.3	[redacted]	20-40 nm		[redacted]
117	ZnO	sunscreen	0.9	TGD (2003)	25	CosIng	20-40 nm		[redacted]
119	ZnO	sunscreen	0.9	TGD (2003)	25	CosIng	20-40 nm		[redacted]

No.	ENP type	Product type	Usage (g/pc/d)	Reference	Conc. (%)	Reference	Mean diameter	Notes	Reference
116	ZnO	sunscreen	0.9	TGD (2003)	9	http://www.cosmeticsdatabase.com/sunproduct.php?prod_id=219586	<200 nm; 20-60 nm	surface area: 12-24 m2/g BET	http://www.cosmeticsdatabase.com/sunproduct.php?prod_id=219586; [redacted]
118	ZnO	sunscreen	0.9	TGD (2003)	9	http://www.cosmeticsdatabase.com/sunproduct.php?prod_id=219586	<200 nm; 20-60 nm	surface area: 12-24 m2/g BET	http://www.cosmeticsdatabase.com/sunproduct.php?prod_id=219586; [redacted]
66	micelles	supplement	0.01	Pravst et al. (2010)	22	[redacted]	30 nm		[redacted]
68	Ca peroxide	toothpaste	2.8	TGD (2003)	15	[redacted]	n/a		
12	SiO2	toothpaste	2.8	TGD (2003)	15	[redacted]	n/a		
122	Ag	washing machine	1.375	Farkas et al. (2008)	100	based on assumption	n/a		
123	Ag	washing machine	1.375	Farkas et al. (2008)	100	based on assumption	n/a		

Appendix 3 – Assumptions/calculations of product usage and NP concentrations in product where no data was available

All values are conservative estimates: maximum values/worst case scenarios

Product		Estimate	Reasoning
Aquarium treatment	ENP conc. (%)	100	product consists to 100% of SiO_2 particles (worst case scenario)
Aquarium treatment	Emission (g/pc/d)	0.002	"very low" based on 1x application per aquarium every 10 years; 30mL of product needed for 3m^2 (for large aquarium; 1 sachet); 10% of UK households own fish; average house size is 2.35: 30g/10years/365d*0.1*2.35 = 0.002 g/pc/d
Car polish	Emission (g/pc/d)	0.3	Assumption: 1x per month polishing/waxing of every car; applied amount: 200g/wax; 28459000 registered cars in the UK (Statistics UK); 61.5M people live in UK (Statistics UK); 200g of wax times 12 months divided by 365d = 6.6g/car/d; 6.6g/car/d times no. of cars, divided by no. of people: 0.3g/pc/d
Clothing (Al)	ENP conc. (%)	0.01	Density Al = 2.70 g·cm^{-3}; 50nm Al layer on membrane (manufacturer's data); assuming therefore each particle has a diameter of 50nm and takes up an area of 50nm*50nm = 2500nm2 = 2500*10^-18 m2; volume of particle: V = π*d3/6 = 65450nm3 = 6.0545*10^-17cm3; volume*density = mass per particle (1.77810^-16g) Using the example of an outdoor jacket assuming that a jacket has measurements of 70cm width and 90cm length = 6300cm^2 times 2 (front and back) = 12600cm^2 area of jacket = 1.26m2; Particle number on jacket: 1.26m2 divided by 2500*10^-18 m2 = 5.04*10^14 particles per jacket; no. of particles times mass per particle = 0.089g/jacket Weight per jacket ~1kg: 0.089g Al/kg ~ 0.01%
Clothing (all)	Emission (g/pc/d)	89	UK consumes ~2M t of textiles per year; this is 0.033t/pc/year and 0.000089t/pc/d = 89 g/pc/d (http://www.scribd.com/doc/7439408/Clothing-Waste-Statistic-Uk)
Clothing (SiO_2)	ENP conc. (%)	4	Best functionality at 4% SiO_2 ENP concentration in product (Wu et al. 2009)

Product		Estimate	Reasoning
Cosmetics (encapsulates)	ENP conc. (%)	4	For lipid nanoparticles in cosmetics 4% (Mueller et al 2010); assumed to be similar for all organic encapsulates in cosmetics
Cosmetics (encapsulates)	Emission (g/pc/d)	0.006	average intake from all sources (mainly natural) is 0.006g/pc/d (Pravst et al 2010)
Food supplement (micelles)	ENP conc. (%)	22	least 22% CoEnzyme Q10 in micelles
Fuel additive	Emission (g/pc/d)	0.007	700M km driven with CeO additive over 3 years by [redacted]; 0.001% CeO added to diesel ENP concentration in fuel: 0.001% or 10ppm (=10mL/L); 700M km driven using CeO additive in 3 years = 233333333km/yr = 639269km/d fuel efficiency (diesel vehicles, average for UK): 0.55L/km; 61.5M people in UK; 0.55L/km times 639269km/d = 351598L/d of which 0.001% is CeO = 3.52L CeO/d divided by 61.5M people = 0.000057mL/pc/d; in mass: volume times density (7.13g/mL) = 0.0004g/pc/d Can multiply up to total bus fleet in the UK by taking total bus miles for the UK, dividing this by the [redacted] bus miles per year and multiplying the emission by the product of this calc. = 2511/146 * 0.0004 = 0.007 g/pc/d
Hair loss treatment (keratin)	Emission (g/pc/d)	0.2	61.5M people live in UK; 1M people suffer from alopecia (http://www.alopeciaonline.org.uk/research.asp; (Hunt et al. 2004); Assuming all sufferers use hair loss products/shampoos. Usage of shampoo is 12 g/c/d for 61.5M people (TGD 2003) – therefore emission for 1 M people: 0.2 g/c/d
Paints (TiO2, FeO, C)	ENP conc. (%)	10	10% TiO_2 concentration in product (MSDS); 10% inclusion rate was also assumed for paints containing other types of particles
Paints (TiO2, FeO, C)	Emission (g/pc/d)	33	12kg/pc/year in UK = 33g/pc/d; ("focus on pigments" 2004)
Socks (Ag)	ENP conc. (%)	0.27	Highest concentration of Ag in one sock =1358ug Ag/g times 2 (pair of socks) = 2716ug Ag/g; this equals 0.27% of nanosilver in a pair of socks (based on Benn & Westerhoff 2008)

Product		Estimate	Reasoning
Sunscreens	ENP conc. (%)	25	if not available, 25% assumed based on maximum concentration allowed by EU
Sunscreens	Emission (g/pc/d	0.9	TGD 2003: 24g/pc/d for 2 weeks a year = 0.9g/pc/d
Washing machine	ENP conc. (%)	100	the product is considered to be the active ingredient (biocide) and not the washing machine itself, therefore it is assumed that the product consists of 100% nanosilver
Washing machine	Emission (g/pc/d)	1.375	washing cycles based on detergent usage (TGD 2003): maximum usage is 18 tasks per week per household; this equals 2.6 tasks per day/household; average household size UK is 2.35 (UK statistics): 2.6tasks per day divided by 2.35 = 1.1 tasks/pc/d (where tasks equals washes); 50L water is used per wash/task (http://www.waterwise.org.uk/reducing_water_wastage_in_the_uk/house_and_garden/washing_clothes.html); 25ug/L Ag released per wash (Farkas et al. 2008): 1.1 tasks/pc/d*50L*25ug Ag/L=1.375g Ag/pc/d

Appendix 4 – Available and estimated market shares of products likely to reach the aquatic environment

Product	Brand	NP type	Market share	Reasoning	Reference
car polish	other	all	<1%	not sold on "high street": Assumption that market share is very low = <1%	
car polish	[redacted]	SiO_2	31.7%	by product: [redacted] sells 120 different car polish/shampoo products from 9 different brands. Out of the 120 products 38 from [redacted] = 31.7%	[redacted]
car polish	[redacted]	SiO_2	25.8%	by product: [redacted] sells 120 different car polish/shampoo products from 9 different brands. Out of the 120 products 31 from [redacted]	[redacted]
car polish	[redacted]	ZnO	31.7%	by product: [redacted] sells 120 different car polish/shampoo products from 9 different brands. Out of the 120 products 38 from [redacted] = 31.7%	[redacted]
car polish	[redacted]	ZnO	25.8%	by product: [redacted] sells 120 different car polish/shampoo products from 9 different brands. Out of the 120 products 31 from [redacted]	[redacted]
coating	Construction incl paint, tiles, glass	All	1%	total: Today approximately 1% of the construction related products on the market have nanoenhanced feature(s).	http://www.observatorynano.eu/project/filesystem/files/ObservatoryNANO_Economic%20assessment_construction_final%20report.pdf
coating	Construction incl paint, tiles, glass	Ceramic	<0.5%	total: Market penetration of nano-enhanced construction ceramics is less than 0.5%.	http://www.observatorynano.eu/project/filesystem/files/ObservatoryNANO_Economic%20assessment_construction_final%20report.pdf
coating (aquarium)	[redacted]	SiO_2	<1%	not sold on "high street": Assumption that market share is very low = <1%	

Product	Brand	NP type	Market share	Reasoning	Reference
cosmetics	[redacted]	C60	0.2%	by product: [redacted] sells 2736 products from 146 brands in the category "skincare" excluding shaving, waxing products. 146 brands have a market share of 0.68% each. Out of [redacted]: 5 products by [redacted] in skincare; see "[redacted]"	[redacted]
cosmetics	other	all	<1%	not sold on "high street": Assumption that market share is very low = <1%	
cosmetics	[redacted]	AIO	0.3%	by product: 2472 "beauty" products at [redacted] of which 8 [redacted] = 0.32%	[redacted]
cosmetics	[redacted]	AIO	0.04%	by product; 1 product out of 2472	[redacted]
cosmetics	[redacted]	ceramid	0.4%	by product: 11 [redacted] products at [redacted] out of 2736 = 0.40%. By brand = 0.68% ("skincare")	[redacted]
cosmetics	[redacted]	encapsulates	0.3%	by product: [redacted] sells 8 [redacted] products out of 2736 "skincare" products = 0.29%	[redacted]
cosmetics	[redacted]	encapsulates	0.8%	by product: No. of all [redacted] products = 23 ("skincare")	[redacted]
cosmetics	[redacted]	encapsulates	2.5%	by product: No. of all [redacted] products = 68 ("skincare")	[redacted]
cosmetics	[redacted]	encapsulates	0.5%	by product: no. of [redacted] products = 13 ("skincare")	[redacted]
cosmetics	[redacted]	SiO_2	0.5%	by product: 1 out of 195 ("skincare")	[redacted]

Product	Brand	NP type	Market share	Reasoning	Reference
cosmetics	[redacted]	ZnO	2.3%	by products: [redacted] sells 2736 products from 146 brands in the category "skincare" excluding shaving, waxing products. 146 brands have a market share of 0.68% each. Out of 2736 products [redacted] has listed 63 products = 2.30%	[redacted]
fuel additive	[redacted]	CeO	100%	intended to use in 7000 bus fleet; In 2009/10 there were 85,800 Public Service Vehicles (PSVs) in use in Great Britain, of which 46,900 were buses and 38,900 were coaches and minibuses. 7000 of 85800 = 8.2%; but not all bus companies taken into account - market share could be higher: unknown = scored as high (1)	[redacted]
hair loss treatment	[redacted]	Keratin	62%	by product: [redacted] sells 79 "hair loss" products from 10 different brands including [redacted]. 49 out of the 79 products are [redacted] products = 62%.	[redacted]
paint	Construction incl paint, tiles, glass	all	1%	total: Today approximately 1% of the construction related products on the market have nanoenhanced feature(s).	http://www.observatorynano.eu/project/filesystem/files/ObservatoryNANO_Economic%20assessment_construction_final%20report.pdf
sunscreens	[redacted]	C60	<1%	not sold on "high street": Assumption that market share is very low = <1%	
sunscreens	all	TiO_2	70%		
sunscreens	all	ZnO	30%		
textiles	all	all	<1%	as a result some of nano-enhanced products are being successfully commercialized. However, and despite being a pioneer in the use of nanotechnology in consumer products, nanotechnology still represents a minor share of the total textile market, with less than 1% of all products incorporating nanotechnology.	http://www.observatorynano.eu/project/filesystem/files/ObNa_Economic%20assessment_textile%20sector_final%20report.pdf
toothpaste	[redacted]	Ca	2.6%	by product: [redacted]: 117 "tooth care" products by 21 brands; [redacted]: 3 products. Market share by products = 2.56%, by brand 4.76%	[redacted]

Product	Brand	NP type	Market share	Reasoning	Reference
toothpaste	[redacted]	SiO_4	3.4%	by product: not exact product, but 4 out of 119 by [redacted]	[redacted]
washing machine	[redacted]	Ag	<1%	not sold on "high street": Assumption that market share is very low = <1%	

[1] "[redacted]" and "[redacted]" - same company

Appendix 5 – Product categorisation and likelihood of exposure after Hansen et al. (2008)

No.	ENP type	Product type	Product category after Hansen et al. (2008)	Exposure category after Hansen et al. (2008)	Likelihood of exposure after Hansen et al. (2008)
68	Ca peroxide	toothpaste	Personal care	Suspended in liquids	1
66	micelles	supplement	Supplement	Suspended in liquids	1
34	SiO2	cosmetics	Cosmetics	Suspended in liquids	1
69	SiO2	coating	Pets	Suspended in liquids	1
96	SiO2	cosmetics	Cosmetics	Suspended in liquids	1
126	SiO2	cosmetics	Cosmetics	Suspended in liquids	1
12	SiO2	toothpaste	Personal care	Suspended in liquids	1
108	TiO2	sunscreen	Sunscreen	Suspended in liquids	1
109	TiO2	sunscreen	Sunscreen	Suspended in liquids	1
114	TiO2	sunscreen	Sunscreen	Suspended in liquids	1
120	TiO2	sunscreen	Sunscreen	Suspended in liquids	1
54	TiO2 (Mn doped)	sunscreen	Sunscreen	Suspended in liquids	1
110	ZnO	sunscreen	Sunscreen	Suspended in liquids	1
115	ZnO	sunscreen	Sunscreen	Suspended in liquids	1
117	ZnO	sunscreen	Sunscreen	Suspended in liquids	1
119	ZnO	sunscreen	Sunscreen	Suspended in liquids	1
35	C60	cosmetics	Cosmetics	Suspended in liquids	1
120	C60	sunscreen	Sunscreen	Suspended in liquids	1
125	C60	cosmetics	Cosmetics	Suspended in liquids	1
33	C60	cosmetics	Cosmetics	Suspended in liquids	1
98	C60 (fulleromes)	cosmetics	Cosmetics	Suspended in liquids	1
14	AlO	cosmetics	Cosmetics	Suspended in liquids	1
16	AlO	cosmetics	Cosmetics	Suspended in liquids	1
51	AlO	cosmetics	Cosmetics	Suspended in liquids	1
39	keratin fibres	hair treatment	Personal care	Suspended in liquids	1
39	keratin fibres	hair treatment	Personal care	Suspended in liquids	1
39	keratin fibres	hair treatment	Personal care	Suspended in liquids	1
39	keratin fibres	hair treatment	Personal care	Suspended in liquids	1
39	keratin fibres	hair treatment	Personal care	Suspended in liquids	1
39	keratin fibres	hair treatment	Personal care	Suspended in liquids	1
5	lipid encapsulates	cosmetics	Cosmetics	Suspended in liquids	1
33	lipid encapsulates	cosmetics	Cosmetics	Suspended in liquids	1
50	lipid encapsulates	cosmetics	Cosmetics	Suspended in liquids	1
97	lipid encapsulates	cosmetics	Cosmetics	Suspended in liquids	1
101	lipid encapsulates	cosmetics	Cosmetics	Suspended in liquids	1
67	TiO2 (Mn doped)	sunscreen	Sunscreen	Suspended in liquids	1
99	ZnO	cosmetics	Cosmetics	Suspended in liquids	1
116	ZnO	sunscreen	Sunscreen	Suspended in liquids	1
118	ZnO	sunscreen	Sunscreen	Suspended in liquids	1
3	C	paint	Construction materials	Suspended in liquids	1
29	Fe2O3	paint	Paint	Suspended in liquids	1
38	silazane	car polish	Automotive	Suspended in liquids	1
21	SiO2	car polish	Automotive	Suspended in liquids	1
38	SiO2	car polish	Automotive	Suspended in liquids	1

No.	ENP type	Product type	Product category after Hansen et al. (2008)	Exposure category after Hansen et al. (2008)	Likelihood of exposure after Hansen et al. (2008)
41	SiO2	car polish	Automotive	Suspended in liquids	1
42	SiO2	car polish	Automotive	Suspended in liquids	1
72	SiO2	car polish	Cleaning/Automotive	Suspended in liquids	1
21	ZnO	car polish	Automotive	Suspended in liquids	1
25	ZnO	car polish	Automotive	Suspended in liquids	1
38	ZnO	car polish	Automotive	Suspended in liquids	1
41	ZnO	car polish	Automotive	Suspended in liquids	1
42	ZnO	car polish	Automotive	Suspended in liquids	1
72	ZnO	car polish	Cleaning/Automotive	Suspended in liquids	1
102	ceramid nanocapsules	cosmetics	Cosmetics	Suspended in liquids	1
11	proteins	cosmetics	Cosmetics	Suspended in liquids	1
100	Vitamin E nanocapsules	cosmetics	Cosmetics	Suspended in liquids	1
22	CeO	fuel additive	Automotive	Suspended in liquids	1
32	SiO2	tooth restorative	Personal care	Suspended in liquids	1
32	Zr	tooth restorative	Personal care	Suspended in liquids	1
53	n/a	sunscreen	Sunscreen	Suspended in liquids	1
58	n/a	cosmetics	Cosmetics	Suspended in liquids	1
61	n/a	cosmetics	Cosmetics	Suspended in liquids	1
111	n/a	sunscreen	Sunscreen	Suspended in liquids	1
112	n/a	sunscreen	Sunscreen	Suspended in liquids	1
113	n/a	sunscreen	Sunscreen	Suspended in liquids	1
37	n/a	tooth restorative	Personal care	Suspended in liquids	1
30	n/a	paint	Paint	Suspended in liquids	1
46	n/a	car polish	Automotive	Suspended in liquids	1
122	Ag	washing machine	Home and garden	Surface bound	2
123	Ag	washing machine	Home and garden	Surface bound	2
13	Ag	clothing	Clothing	Surface bound	2
63	Ag	clothing	Clothing	Surface bound	2
64	Ag	clothing	Clothing	Surface bound	2
65	Ag	clothing	Clothing	Surface bound	2
28	TiO2	paint	Paint	Surface bound	2
15	ceramic	coating	Paint	Surface bound	2
2	TiO2	coating	Cleaning	Surface bound	2
55	TiO2	coating	Construction materials	Surface bound	2
60	TiO2	coating	Cleaning	Surface bound	2
1	Ag	clothing	Clothing	Surface bound	2
9	Ag	clothing	Sporting goods	Surface bound	2
94	Al	clothing	Clothing	Surface bound	2
2	Ag	coating	Cleaning	Surface bound	2
6	Ag	water filtration	Filtration	Surface bound	2
7	Ag	water filtration	Filtration	Surface bound	2
6	C	water filtration	Filtration	Surface bound	2
6	Cu	water filtration	Filtration	Surface bound	2
6	ZnO	water filtration	Filtration	Surface bound	2
7	C	water filtration	Filtration	Surface bound	2
4	Ag	wound dressing	Personal care	Surface bound	2
17	Ag	vacuum cleaner	Home and garden	Surface bound	2
121	Ag	vacuum cleaner	Home and garden	Surface bound	2
4	C	wound dressing	Personal care	Surface bound	2

No.	ENP type	Product type	Product category after Hansen et al. (2008)	Exposure category after Hansen et al. (2008)	Likelihood of exposure after Hansen et al. (2008)
74	ceramic	paper	Cameras and Film	Surface bound	2
20	clay	sporting goods	Sporting goods	Surface bound	2
8	TiO2	hair straighter	Cosmetics	Surface bound	2
56	TiO2	hair straighter	Cosmetics	Surface bound	2
26	n/a	razor	Personal care	Surface bound	2
40	n/a	cosmetics	Personal care	Surface bound	2
124	n/a	sporting goods	Sporting goods	Surface bound	2
92	SiO2	clothing	Clothing	Suspended in solids	3
93	SiO2	clothing	Clothing	Suspended in solids	3
95	SiO2	clothing	Clothing	Suspended in solids	3
18	C	Sporting goods	Sporting goods	Suspended in solids	3
31	C	Sporting goods	Sporting goods	Suspended in solids	3
27	C60	Sporting goods	Sporting goods	Suspended in solids	3
73	clay	Sporting goods	Sporting goods	Suspended in solids	3
19	CNT	Sporting goods	Sporting goods	Suspended in solids	3
24	CNT	Sporting goods	Sporting goods	Suspended in solids	3
43	CNT	Sporting goods	Sporting goods	Suspended in solids	3
44	CNT	Sporting goods	Sporting goods	Suspended in solids	3
45	CNT	Sporting goods	Sporting goods	Suspended in solids	3
47	CNT	Sporting goods	Sporting goods	Suspended in solids	3
48	CNT	Sporting goods	Sporting goods	Suspended in solids	3
49	CNT	Sporting goods	Sporting goods	Suspended in solids	3
52	CNT	Sporting goods	Sporting goods	Suspended in solids	3
57	CNT	Sporting goods	Sporting goods	Suspended in solids	3
70	CNT	Sporting goods	Sporting goods	Suspended in solids	3
71	CNT	Sporting goods	Sporting goods	Suspended in solids	3
103	CNT	Sporting goods	Sporting goods	Suspended in solids	3
27	Ti	Sporting goods	Sporting goods	Suspended in solids	3
31	Ti	Sporting goods	Sporting goods	Suspended in solids	3
10	n/a	clothing	Sporting goods	Suspended in solids	3
23	n/a	Sporting goods	Sporting goods	Suspended in solids	3
75	Ag	air filtration	Filtration	Unclassifiable	4
104	Ag	mobile phone	Mobile devices and Communications	Unclassifiable	4
105	Ag	refrigerator	Storage	Unclassifiable	4
106	Ag	refrigerator	Storage	Unclassifiable	4
107	Ag	refrigerator	Storage	Unclassifiable	4
59	Ag	refrigerator	Storage	Unclassifiable	4
36	n/a	clothing	Clothing	Unclassifiable	4
76	n/a	clothing	Clothing	Unclassifiable	4
77	n/a	clothing	Clothing	Unclassifiable	4
78	n/a	clothing	Clothing	Unclassifiable	4
79	n/a	clothing	Clothing	Unclassifiable	4
80	n/a	clothing	Clothing	Unclassifiable	4
81	n/a	clothing	Clothing	Unclassifiable	4
82	n/a	clothing	Clothing	Unclassifiable	4
83	n/a	clothing	Clothing	Unclassifiable	4
84	n/a	clothing	Clothing	Unclassifiable	4
85	n/a	clothing	Clothing	Unclassifiable	4
86	n/a	clothing	Clothing	Unclassifiable	4
87	n/a	clothing	Clothing	Unclassifiable	4
88	n/a	clothing	Clothing	Unclassifiable	4
89	n/a	clothing	Clothing	Unclassifiable	4
90	n/a	clothing	Clothing	Unclassifiable	4
91	n/a	clothing	Clothing	Unclassifiable	4
62	n/a	car	Automotive	Unclassifiable	4

Appendix 6 – Product Ranking (qualitative) based on likelihood to reach drinking water sources

No.	ENP type	Product type	Release pattern	Conc. (qual)	Usage (qual)	Release (qual)	Market penetration (%)	Score Conc.	Score Usage	Score Release	Score Market penetr.	Total score
108	TiO2	Sunscreen	down the drain	high	low	highly likely	high	1	3	1	1	6
109	TiO2	Sunscreen	down the drain	high	low	highly likely	high	1	3	1	1	6
114	TiO2	Sunscreen	down the drain	high	low	highly likely	high	1	3	1	1	6
120	TiO2	Sunscreen	down the drain	high	low	highly likely	high	1	3	1	1	6
54	TiO2 (Mn doped)	Sunscreen	down the drain	high	low	highly likely	high	1	3	1	1	6
110	ZnO	Sunscreen	down the drain	high	low	highly likely	medium	1	3	1	2	7
115	ZnO	Sunscreen	down the drain	high	low	highly likely	medium	1	3	1	2	7
117	ZnO	Sunscreen	down the drain	high	low	highly likely	medium	1	3	1	2	7
119	ZnO	Sunscreen	down the drain	high	low	highly likely	medium	1	3	1	2	7
68	Ca peroxide	Toothpaste	down the drain	high	medium	highly likely	low	1	2	1	3	7
12	SiO2	Toothpaste	down the drain	high	medium	highly likely	low	1	2	1	3	7
99	ZnO	Cosmetics	down the drain	medium	high	highly likely	low	2	1	1	3	7
39	keratin fibres	hair loss treatment	down the drain	medium	low	highly likely	high	2	3	1	1	7
67	TiO2 (Mn doped)	Sunscreen	down the drain	medium	low	highly likely	high	2	3	1	1	7
3	C	Paint	run off	medium	high	highly likely	very low	2	1	1	4	8
29	Fe2O3	Paint	run off	medium	high	highly likely	very low	2	1	1	4	8
41	SiO2	car polish	run off	medium	low	highly likely	medium	2	3	1	2	8
72	SiO2	car polish	run off	medium	low	highly likely	medium	2	3	1	2	8
41	ZnO	car polish	run off	medium	low	highly likely	medium	2	3	1	2	8
72	ZnO	car polish	run off	medium	low	highly likely	medium	2	3	1	2	8
116	ZnO	Sunscreen	down the drain	medium	low	highly likely	medium	2	3	1	2	8
118	ZnO	Sunscreen	down the drain	medium	low	highly likely	medium	2	3	1	2	8
34	SiO2	Cosmetics	down the drain	high	low	highly likely	very low	1	3	1	4	9
126	SiO2	Cosmetics	down the drain	high	low	highly likely	very low	1	3	1	4	9
123	Ag	washing machine	down the drain	high	medium	likely	very low	1	2	2	4	9

No.	ENP type	Product type	Release pattern	Conc. (qual)	Usage (qual)	Release (qual)	Market penetration (%)	Score Conc.	Score Usage	Score Release	Score Market penetr.	Total score
15	ceramic	Coating	run off	medium	high	likely	very low	2	1	2	4	9
2	TiO2	Coating	run off	medium	high	likely	very low	2	1	2	4	9
60	TiO2	Coating	run off	medium	high	likely	very low	2	1	2	4	9
55	TiO2	Coating	run off	medium	high	likely	very low	2	1	2	4	9
28	TiO2	Paint	down the drain	medium	high	likely	very low	2	1	2	4	9
97	lipid encapsulates	Cosmetics	down the drain	medium	low	highly likely	low	2	3	1	3	9
11	Proteins	Cosmetics	down the drain	unknown	low	highly likely	very low	1	3	1	4	9
102	ceramid nanocapsules	Cosmetics	down the drain	unknown	low	highly likely	very low	1	3	1	4	9
100	Vitamin E nanocapsules	Cosmetics	down the drain	unknown	low	highly likely	very low	1	3	1	4	9
66	Micelles	supplement	down the drain	high	very low	highly likely	very low	1	4	1	4	10
69	SiO2	Coating	down the drain	high	very low	highly likely	very low	1	4	1	4	10
13	Ag	Clothing	down the drain	low	high	likely	very low	3	1	2	4	10
65	Ag	Clothing	down the drain	low	high	likely	very low	3	1	2	4	10
93	SiO2	Clothing	down the drain	medium	high	unlikely	very low	2	1	3	4	10
95	SiO2	Clothing	down the drain	medium	high	unlikely	very low	2	1	3	4	10
92	SiO2	Clothing	down the drain	medium	high	unlikely	very low	2	1	3	4	10
33	lipid encapsulates	Cosmetics	down the drain	medium	low	highly likely	very low	2	3	1	4	10
38	silazane	car polish	run off	medium	low	highly likely	very low	2	3	1	4	10
21	SiO2	car polish	run off	medium	low	highly likely	very low	2	3	1	4	10
42	SiO2	car polish	run off	medium	low	highly likely	very low	2	3	1	4	10
38	SiO2	car polish	run off	medium	low	highly likely	very low	2	3	1	4	10
21	ZnO	car polish	run off	medium	low	highly likely	very low	2	3	1	4	10
42	ZnO	car polish	run off	medium	low	highly likely	very low	2	3	1	4	10
38	ZnO	car polish	run off	medium	low	highly likely	very low	2	3	1	4	10
16	AlO	Cosmetics	down the drain	medium	low	highly likely	very low	2	3	1	4	10
51	AlO	Cosmetics	down the drain	medium	low	highly likely	very low	2	3	1	4	10
101	lipid encapsulates	Cosmetics	down the drain	medium	low	highly likely	very low	2	3	1	4	10

No.	ENP type	Product type	Release pattern	Conc. (qual)	Usage (qual)	Release (qual)	Market penetration (%)	Score Conc.	Score Usage	Score Release	Score Market penetr.	Total score
50	lipid encapsulates	Cosmetics	down the drain	medium	low	highly likely	very low	2	3	1	4	10
22	CeO	fuel additive	run off	very low	very low	highly likely	unknown	4	4	1	1	10
35	C60	Cosmetics	down the drain	low	low	highly likely	very low	3	3	1	4	11
125	C60	Cosmetics	down the drain	low	low	highly likely	very low	3	3	1	4	11
120	C60	Sunscreen	down the drain	low	low	highly likely	very low	3	3	1	4	11
98	C60 (fulleromes)	Cosmetics	down the drain	low	low	highly likely	very low	3	3	1	4	11
33	C60	Cosmetics	down the drain	low	low	highly likely	very low	3	3	1	4	11
14	AlO	Cosmetics	down the drain	medium	very low	highly likely	very low	2	4	1	4	11
5	lipid encapsulates	Cosmetics	down the drain	medium	very low	highly likely	very low	2	4	1	4	11
1	Ag	Clothing	down the drain	very low	high	likely	very low	4	1	2	4	11
9	Ag	Clothing	down the drain	very low	high	likely	very low	4	1	2	4	11
2	Ag	Coating	run off	very low	high	likely	very low	4	1	2	4	11
94	Al	Clothing	down the drain	very low	high	likely	very low	4	1	2	4	11

Appendix 7 – Estimated concentrations in raw and treated drinking water

Estimated concentrations in raw and treated drinking water as a measure of mass concentration (ug/L)

type	application	removal WWTP	WWTP effluent ug/L	WWTP biosolids ug/L	WTP influent ug/L	WTP conventional ug/L	WTP membrane ug/L	WTP filtration ug/L
Aluminium & aluminium oxide	all products	0%	1.29E+00	0	1.29E-01	1.29E-03	1.29E-05	4.08E-03
		97%	3.87E-02	1.25E+00	3.87E-03	3.87E-05	3.87E-07	1.22E-04
Ca peroxide	Toothpaste	0%	7.17E+01	0	7.17E+00	7.17E-02	7.17E-04	2.27E-01
		97%	2.15E+00	6.95E+01	2.15E-01	2.15E-03	2.15E-05	6.80E-03
Carbon & C60	all products	0%	2.21E+02	0.00E+00	2.21E+01	2.21E-01	2.21E-03	6.98E-01
		97%	6.62E+00	2.14E+02	6.62E-01	6.62E-03	6.62E-05	2.09E-02
Carbon	all products	0%	2.20E+02	0.00E+00	2.20E+01	2.20E-01	2.20E-03	6.96E-01
		97%	6.60E+00	2.13E+02	6.60E-01	6.60E-03	6.60E-05	2.09E-02
C60	all products	0%	5.77E-01	0	5.77E-02	5.77E-04	5.77E-06	1.82E-03
		79%	1.21E-01	4.56E-01	1.21E-02	1.21E-04	1.21E-06	3.83E-04
		97%	1.73E-02	5.59E-01	1.73E-03	1.73E-05	1.73E-07	5.47E-05
Cerium oxide	all products	0%	4.67E-04	0	4.67E-05	4.67E-07	4.67E-09	1.48E-06
		95%	2.33E-05	4.43E-04	2.33E-06	2.33E-08	2.33E-10	7.38E-08
		97%	1.40E-05	4.53E-04	1.40E-06	1.40E-08	1.40E-10	4.43E-08
Ceramic	Coating	0%	3.67E+02	0	3.67E+01	3.67E-01	3.67E-03	1.16E+00
		97%	1.10E+01	3.56E+02	1.10E+00	1.10E-02	1.10E-04	3.48E-02
Encapsulates	all products	0%	1.41E+01	0	1.41E+00	1.41E-02	1.41E-04	4.45E-02
		97%	5.92E-01	1.35E+01	5.92E-02	5.92E-04	5.92E-06	1.87E-03
Iron oxide	Paint	0%	2.20E+02	0	2.20E+01	2.20E-01	2.20E-03	6.96E-01
		97%	6.60E+00	2.13E+02	6.60E-01	6.60E-03	6.60E-05	2.09E-02
Keratin	all products	0%	8.27E+01	0	8.27E+00	8.27E-02	8.27E-04	2.61E-01
		97%	2.48E+00	8.02E+01	2.48E-01	2.48E-03	2.48E-05	7.84E-03
Silazane	car polish	0%	1.00E+00	0	1.00E-01	1.00E-03	1.00E-05	3.16E-03
		97%	3.00E-02	9.70E-01	3.00E-03	3.00E-05	3.00E-07	9.49E-05
Silica	all products	0%	4.00E+02	0	4.00E+01	4.00E-01	4.00E-03	1.26E+00
		97%	1.20E+01	3.88E+02	1.20E+00	1.20E-02	1.20E-04	3.79E-02
Silver	all products	0%	1.07E+02	0	1.07E+01	1.07E-01	1.07E-03	3.39E-01

type	application	removal WWTP	WWTP effluent ug/L	WWTP biosolids ug/L	WTP influent ug/L	WTP conventional ug/L	WTP membrane ug/L	WTP filtration ug/L
		39%	6.54E+01	4.18E+01	6.54E+00	6.54E-02	6.54E-04	2.07E-01
		97%	3.21E+00	1.04E+02	3.21E-01	3.21E-03	3.21E-05	1.02E-02
Titanium oxide	all products	0%	1.64E+03	0.00E+00	1.64E+02	1.64E+00	1.64E-02	5.18E+00
		23%	1.26E+03	3.76E+02	1.26E+02	1.26E+00	1.26E-02	3.99E+00
		97%	4.91E+01	1.59E+03	4.91E+00	4.91E-02	4.91E-04	1.55E-01
Titanium oxide	Sunscreens	0%	1.05E+03	0	1.05E+02	1.05E+00	1.05E-02	3.32E+00
		23%	8.09E+02	2.42E+02	8.09E+01	8.09E-01	8.08E-03	2.56E+00
		97%	3.15E+01	1.02E+03	3.15E+00	3.15E-02	3.15E-04	9.96E-02
Zinc oxide	all products	0%	6.36E+02	0	6.36E+01	6.36E-01	6.35E-03	2.01E+00
		97%	1.91E+01	6.16E+02	1.91E+00	1.91E-02	1.91E-04	6.03E-02
Zinc oxide	Sunscreens	0%	4.50E+02	0	4.50E+01	4.50E-01	4.50E-03	1.42E+00
		97%	1.35E+01	4.37E+02	1.35E+00	1.35E-02	1.35E-04	4.27E-02

Estimated concentrations in raw and treated drinking water as a measure of particle number concentration (#/L)

Type	application	removal WWTP	Particle size nm	WWTP effluent #/L	WWTP biosolids #/L	WTP influent #/L	WTP conventional #/L	WTP membrane #/L	WTP filtration #/L
Aluminium & aluminium oxide	all products	0%	50	7.30E+09	0	7.30E+08	7.30E+06	7.30E+04	2.31E+07
		0%	5000	7.30E+03	0	7.30E+02	7.30E+00	7.30E-02	2.31E+01
		97%	50	2.19E+08	7.08E+09	2.19E+07	2.19E+05	2.19E+03	6.92E+05
		97%	5000	2.19E+02	7.08E+03	2.19E+01	2.19E-01	2.19E-03	6.92E-01
C60	all products	0%	20	8.00E+10	0	8.00E+09	8.00E+07	8.00E+05	2.53E+08
		0%	80	1.25E+09	0	1.25E+08	1.25E+06	1.25E+04	3.95E+06
		79%	20	1.68E+10	6.32E+10	1.68E+09	1.68E+07	1.68E+05	5.32E+07
		79%	80	2.63E+08	9.88E+08	2.63E+07	2.63E+05	2.63E+03	8.31E+05
		97%	20	2.40E+09	7.76E+10	2.40E+08	2.40E+06	2.40E+04	7.59E+06
		97%	80	3.75E+07	1.21E+09	3.75E+06	3.75E+04	3.75E+02	1.19E+05
Cerium oxide	all products	0%	8	2.44E+08	0	2.44E+07	2.44E+05	2.44E+03	7.72E+05
		95%	8	1.22E+07	2.32E+08	1.22E+06	1.22E+04	1.22E+02	3.86E+04
		97%	8	7.32E+06	2.37E+08	7.32E+05	7.32E+03	7.32E+01	2.32E+04
Iron oxide	Paint	0%	10	8.13E+13	0	8.13E+12	8.13E+10	8.13E+08	2.57E+11
		97%	10	2.44E+12	7.88E+13	2.44E+11	2.44E+09	2.44E+07	7.71E+09
Silica	all products	0%	10	2.90E+14	0	2.90E+13	2.90E+11	2.90E+09	9.16E+11
		0%	1000	2.90E+08	0.00E+00	2.90E+07	2.90E+05	2.90E+03	9.16E+05
Silica	all products	97%	10	8.69E+12	2.81E+14	8.69E+11	8.69E+09	8.69E+07	2.75E+10
		97%	1000	8.69E+06	2.81E+08	8.69E+05	8.69E+03	8.69E+01	2.75E+04
Silver	all products	0%	25	1.25E+12	0	1.25E+11	1.25E+09	1.25E+07	3.95E+09
		0%	150	5.78E+09	0	5.78E+08	5.78E+06	5.78E+04	1.83E+07
		39%	25	7.62E+11	4.87E+11	7.62E+10	7.62E+08	7.62E+06	2.41E+09
		39%	150	3.53E+09	2.25E+09	3.53E+08	3.53E+06	3.53E+04	1.12E+07
		97%	25	3.75E+10	1.21E+12	3.75E+09	3.75E+07	3.75E+05	1.18E+08
		97%	150	1.73E+08	5.61E+09	1.73E+07	1.73E+05	1.73E+03	5.48E+05
Titanium oxide	sunscreens	0%	20	5.93E+13	0	5.93E+12	5.93E+10	5.93E+08	1.87E+11
		0%	70	1.38E+12	0	1.38E+11	1.38E+09	1.38E+07	4.37E+09

Type	application	removal WWTP	Particle size nm	WWTP effluent #/L	WWTP biosolids #/L	WTP influent #/L	WTP conventional #/L	WTP membrane #/L	WTP filtration #/L
		23%	20	4.56E+13	1.36E+13	4.56E+12	4.56E+10	4.56E+08	1.44E+11
		23%	70	1.06E+12	3.18E+11	1.06E+11	1.06E+09	1.06E+07	3.37E+09
		97%	20	1.78E+12	5.75E+13	1.78E+11	1.78E+09	1.78E+07	5.62E+09
		97%	70	4.15E+10	1.34E+12	4.15E+09	4.15E+07	4.15E+05	1.31E+08
Zinc oxide	sunscreens	0%	20	1.92E+13	0	1.92E+12	1.92E+10	1.92E+08	6.06E+10
		0%	200	1.92E+10	0	1.92E+09	1.92E+07	1.92E+05	6.06E+07
		97%	20	5.75E+11	1.86E+13	5.75E+10	5.75E+08	5.75E+06	1.82E+09
		97%	200	5.75E+08	1.86E+10	5.75E+07	5.75E+05	5.75E+03	1.82E+06

Appendix 8 – Exposure to ENPs via drinking water compared to other routes of exposure (qualitative)

							Consumer Contact			Exposure Route									
Industry & Product	Ident	Material	Conc	Surface Bound	Susp. in Liquid	Susp. in Solids	None Intended / None Likely	None Intended / Possible	Intended and Likely	Inhaln	Dermal	Ingesn	Potential for Release	Concn%	Contact	Release Potential	Exposure Rating	Release to DW Rating	Combined score
Automotive																			
[redacted]	21	SiO2	Medium		1				1		1		Highly Likely	2	1	1	4	6	2
[redacted]	21	ZnO	Medium		1				1		1		Highly Likely	2	1	1	4	6	2
[redacted]	25	ZnO	Medium		1				1		1		Highly Likely	2	1	1	4	6	2
[redacted]	38	Silazane	medium		1				1		1		Highly Likely	2	1	1	4	6	2
[redacted]	38	SiO2	medium		1				1		1		Highly Likely	2	1	1	4	6	2
[redacted]	38	ZnO	medium		1				1		1		Highly Likely	2	1	1	4	6	2
[redacted]	41	SiO2	medium		1				1		1		Highly Likely	2	1	1	4	6	2
[redacted]	41	ZnO	medium		1				1		1		Highly Likely	2	1	1	4	6	2
[redacted]	42	SiO2	medium		1				1		1		Highly Likely	2	1	1	4	6	2
[redacted]	42	ZnO	medium		1				1		1		Highly Likely	2	1	1	4	6	2
[redacted]	72	SiO2	medium		1				1		1		Highly Likely	2	1	1	4	6	2
[redacted]	72	ZnO	medium		1				1		1		Highly Likely	2	1	1	4	6	2
[redacted]	46	N.S			1				1		1		Highly Likely	5	1	1	7	0	-7
[redacted]	22	CeO	very low		1			1		2	1		Unlikely	4	2	3	9	9	0
[redacted]	62	N.S					1						Unlikely	5	3	3	11	0	-11
Cameras and Film																			
[redacted]	74	N.S		1					1		1		Unlikely	5	1	3	9	0	-9
Cleaning																			
[redacted]	2	TiO2	medium	1					1		1		Unlikely	2	1	3	6	0	-6
[redacted]	60	TiO2	medium	1					1		1		Unlikely	2	1	3	6	5	-1
[redacted]	2	Ag	very low	1					1		1		Unlikely	4	1	3	8	7	-1
Clothing																			
[redacted]	76	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	77	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	78	N.S							1	2	1		Unlikely	2	1	3	6	0	-6

							Consumer Contact			Exposure Route									
Industry & Product	Ident	Material	Conc	Surface Bound	Susp. in Liquid	Susp. in Solids	None Intended / None Likely	None Intended / Possible	Intended and Likely	Inhaln	Dermal	Ingesn	Potential for Release	Concn%	Contact	Release Potential	Exposure Rating	Release to DW Rating	Combined score
Various Clothing Lines	79	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	80	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	81	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	82	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	83	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	84	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	85	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	86	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	87	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	88	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	89	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	90	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	91	N.S							1	2	1		Unlikely	2	1	3	6	0	-6
Various Clothing Lines	92	SiO2	medium			1			1	2	1		Unlikely	2	1	3	6	6	0
Various Clothing Lines	93	SiO2	medium			1			1	2	1		Unlikely	2	1	3	6	6	0
Various Clothing Lines	95	SiO2	medium			1			1	2	1		Unlikely	2	1	3	6	6	0
Business Black Sock, Sport Anklet Sock, Sport Half Length Sock, Sport Half Length Sock, Sports Long Sock	13	Ag	low	1					1		1		Unlikely	3	1	3	7	6	-1
[redacted]	63	Ag	low	1					1		1		Unlikely	3	1	3	7	6	-1
[redacted]	64	Ag	low	1					1		1		Unlikely	3	1	3	7	6	-1
[redacted]	65	Ag	low	1					1		1		Unlikely	3	1	3	7	6	-1
[redacted]	1	Ag	very low	1					1		1		Unlikely	4	1	3	8	7	-1
Various Clothing Lines	94	Al	very low	1					1	2	1		Unlikely	4	1	3	8	7	-1
[redacted]	36	N.S							1		1		Unlikely	5	1	3	9	0	-9
Communications																			
Various mobile phones	104	N.S					1						Unlikely	5	3	3	11	0	-11

							Consumer Contact			Exposure Route									
Industry & Product	**Ident**	**Material**	**Conc**	**Surface Bound**	**Susp. in Liquid**	**Susp. in Solids**	**None Intended / None Likely**	**None Intended / Possible**	**Intended and Likely**	**Inhaln**	**Dermal**	**Ingesn**	**Potential for Release**	**Concn%**	**Contact**	**Release Potential**	**Exposure Rating**	**Release to DW Rating**	**Combined score**
Construction Materials																			
A range of nanotechnology surface coating and paints	3	Carbon	medium		1			1			1		Likely	2	2	3	7	4	-3
[redacted]	55	TiO2	medium	1			1						Unlikely	2	3	3	8	5	-3
Cosmetics																			
[redacted]	34	SiO2	high		1				1		1		Highly Likely	1	1	1	3	5	2
Various cosmetics	96	SiO2	high		1				1		1		Highly Likely	1	1	1	3	5	2
[redacted]	126	SiO2	high		1				1		1		Highly Likely	1	1	1	3	5	2
[redacted]	5	Lipid	medium		1				1		1		Highly Likely	2	1	1	4	7	3
[redacted]	14	AlO	medium		1				1		1		Highly Likely	2	1	1	4	7	3
[redacted]	16	AlO	medium		1				1		1		Highly Likely	2	1	1	4	7	3
[redacted]	33	Lipid	medium		1				1		1		Highly Likely	2	1	1	4	6	2
[redacted]	50	Lipid	medium		1				1		1		Highly Likely	2	1	1	4	6	2
[redacted]	51	AlO	medium		1				1		1		Highly Likely	2	1	1	4	6	2
various cosmetics	97	lipid	medium		1				1		1		Highly Likely	2	1	1	4	6	2
Various cosmetics [redacted]	99	ZnO	medium		1				1		1		Highly Likely	2	1	1	4	4	0
[redacted]	8	N.S							1		1		Highly Likely	3	1	1	5	0	-5
[redacted]	33	C60	low		1				1		1		Highly Likely	3	1	1	5	0	-5
[redacted]	35	C60	low		1				1		1		Highly Likely	3	1	1	5	7	2
[redacted]	58	N.S							1		1	2	Highly Likely	3	1	1	5	0	-5
[redacted]	61	N.S							1		1		Highly Likely	3	1	1	5	0	-5
Various cosmetics	98	C60	low		1				1		1		Highly Likely	3	1	1	5	7	2
[redacted]	102	Ceramid	unknown		1				1		1		Highly Likely	5	1	1	7	9	2

							Consumer Contact			Exposure Route									
Industry & Product	Ident	Material	Conc	Surface Bound	Susp. in Liquid	Susp. in Solids	None Intended / None Likely	None Intended / Possible	Intended and Likely	Inhaln	Dermal	Ingesn	Potential for Release	Concn%	Contact	Release Potential	Exposure Rating	Release to DW Rating	Combined score
[redacted]	125	C60	low		1				1		1		Highly Likely	3	1	1	5	7	2
[redacted]	101	Lipid	medium		1				1		1		Highly Likely	3	1	1	5	6	1
[redacted]	11	Proteins	unknown		1				1		1		Highly Likely	5	1	1	7	9	2
[redacted]	100	Vitamin E	unknown		1				1		1		Highly Likely	5	1	1	7	9	2
[redacted]	56	N.S							1				Unlikely	3	1	3	7	0	-7
Filtration																			
[redacted]	6	N.S						1					Unlikely	5	2	3	10	0	-10
[redacted]	7	N.S						1					Unlikely	5	2	3	10	0	-10
Various Air conditioning units	75	N.S						1					Unlikely	5	2	3	10	0	-10
Various Vacuum Cleaners	121	N.S						1		2	1		Unlikely	5	2	3	10	0	-10
Various Washing Machines	122	Ag	high	1			1				1		Highly Likely	1	1	1	3	5	2
[redacted]	123	Ag	high	1			1				1		Highly Likely	1	1	1	3	5	2
[redacted]	17	N.S						1		2	1		Unlikely	5	2	3	10	0	-10
Various Vacuum Cleaners	121	N.S						1		2	1		Unlikely	5	2	3	10	0	-10
Paints and Coatings																			
[redacted]	15	Ceramic	medium	2	1			1		2	1		Likely	2	2	2	6	5	-1
[redacted]	29	Fe2O3	medium	2	1			1		2	1		Likely	2	2	2	6	4	-2
[redacted]	28	TiO2	medium	1			1						Unlikely	2	2	3	7	5	-2
Interior and exterior paint	30	N.S		2	1			1		2	1		Likely	5	2	2	9	0	-9
Personal Care																			
[redacted]	68	Calcium	high		1				1			1	Highly Likely	1	1	1	3	4	1
[redacted]	12	SiO2	high		1				1			1	Highly Likely	1	1	1	3	4	1
[redacted]	39	keratin	medium		1				1		1		Highly Likely	2	1	1	4	4	0
[redacted]	39	keratin	medium		1				1		1		Highly Likely	2	1	1	4	4	0

Industry & Product	Ident	Material	Conc	Surface Bound	Susp. in Liquid	Susp. in Solids	Consumer Contact			Exposure Route			Potential for Release	Concn%	Contact	Release Potential	Exposure Rating	Release to DW Rating	Combined score
							None Intended / None Likely	None Intended / Possible	Intended and Likely	Inhaln	Dermal	Ingesn							
[redacted]	39	keratin	medium		1				1		1		Highly Likely	2	1	1	4	4	0
[redacted]	39	keratin	medium		1				1		1		Highly Likely	2	1	1	4	4	0
[redacted]	39	keratin	medium		1				1		1		Highly Likely	2	1	1	4	4	0
[redacted]	39	keratin	medium		1				1		1		Highly Likely	2	1	1	4	4	0
[redacted]	32	N.S							1		1		Highly Likely	3	1	1	5	0	-5
[redacted]	40	N.S			1				1		1		Highly Likely	3	1	1	5	0	-5
[redacted]	4	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	37	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	26	N.S							1		1		Unlikely	4	1	3	8	0	-8
Pets																			
[redacted]	69	SiO2	high		1			1			1		Highly Likely	1	2	1	4	6	2
Sporting Goods																			
[redacted]	10	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	20	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	23	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	24	N.S							1		1		Unlikely	3	1	3	7	0	-7
Golf clubs	27	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	31	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	43	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	44	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	45	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	47	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	48	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	49	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	52	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	57	N.S							1		1		Unlikely	3	1	3	7	0	-7
Tennis Rackets	70	N.S							1		1		Unlikely	3	1	3	7	0	-7

Industry & Product	Ident	Material	Conc	Surface Bound	Susp. in Liquid	Susp. in Solids	Consumer Contact: None Intended / None Likely	Consumer Contact: None Intended / Possible	Consumer Contact: Intended and Likely	Exposure Route: Inhaln	Exposure Route: Dermal	Exposure Route: Ingesn	Potential for Release	Concn%	Contact	Release Potential	Exposure Rating	Release to DW Rating	Combined score
Tennis Racket	71	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	73	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	103	N.S							1		1		Unlikely	3	1	3	7	0	-7
[redacted]	124	N.S							1		1		Unlikely	3	1	3	7	0	-7
Bath and Sports Towels	9	Ag	very low	1					1	1	1		Unlikely	4	1	3	8	7	-1
[redacted]	18	N.S					1						Unlikely	5	2	3	10	0	-10
Different bicycle parts [redacted]	19	N.S						1			1		Unlikely	5	2	3	10	0	-10
Storage																			
[redacted]	59	N.S					1						Unlikely	5	3	3	11	0	-11
Various Refrigerators	105	N.S					1						Unlikely	5	3	3	11	0	-11
Various Refrigerators	106	N.S					1						Unlikely	5	3	3	11	0	-11
Various Refrigerators	107	N.S					1						Unlikely	5	3	3	11	0	-11
Sunscreen																			
[redacted]	54	TiO2 (Mn)	high		1				1		1		Highly Likely	1	1	1	3	5	2
Various Sunscreens	108	TiO2	high		1				1		1		Highly Likely	1	1	1	3	5	2
Various Sunscreens	109	TiO2	high		1				1		1		Highly Likely	1	1	1	3	5	2
Various Sunscreens	110	ZnO	high		1				1		1		Highly Likely	1	1	1	3	5	2
Various Sunscreens	111	N.S	high						1		1		Highly Likely	1	1	1	3	0	-3
Various Sunscreens	112	N.S	high						1		1		Highly Likely	1	1	1	3	0	-3
Various Sunscreens	113	N.S	high						1		1		Highly Likely	1	1	1	3	0	-3
Various Sunscreens	114	TiO2	high		1				1		1		Highly Likely	1	1	1	3	5	2
Various Sunscreens	115	ZnO	high		1				1		1		Highly Likely	1	1	1	3	5	2
Various Sunscreens	117	ZnO	high		1				1		1		Highly Likely	1	1	1	3	5	2
Various Sunscreens	119	ZnO	high		1				1		1		Highly Likely	1	1	1	3	5	2
Various Sunscreens	120	TiO2	high		1				1		1		Highly Likely	1	1	1	3	5	2
[redacted]	67	TiO2 (Mn)	medium		1				1		1		Highly Likely	2	1	1	4	6	2

							Consumer Contact			Exposure Route									
Industry & Product	**Ident**	**Material**	**Conc**	**Surface Bound**	**Susp. in Liquid**	**Susp. in Solids**	**None Intended / None Likely**	**None Intended / Possible**	**Intended and Likely**	**Inhaln**	**Dermal**	**Ingesn**	**Potential for Release**	**Concn%**	**Contact**	**Release Potential**	**Exposure Rating**	**Release to DW Rating**	**Combined score**
Various Sunscreens	116	ZnO	medium		1				1		1		Highly Likely	2	1	1	4	6	2
Various Sunscreens	118	ZnO	medium		1				1		1		Highly Likely	2	1	1	4	6	2
	120	C60	low						1		1		Highly Likely	3	1	1	5	0	-5
[redacted]	53	N.S							1		1		Highly Likely	5	1	1	7	0	-7
Supplement																			
[redacted]	66	CoEnzyme	high		1				1			1	Highly Likely	1	1	1	3	6	3