



National Institute
for Public Health
and the Environment

Letter report 340370001/2009

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Exposure to nanomaterials in consumer products

RIVM Letter Report 340370001/2009

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This investigation has been performed by order and for the account of Food and Consumer Products Safety Authority, within the framework of V/340370: Health risks of the application of nanotechnology in consumer products

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Abstract

Exposure to nanomaterials in consumer products

Nanomaterials are developed and used in a wide variety of applications including consumer products because they have new specific properties that can improve the functionality of the product. There are already several consumer products containing nanomaterials on the Dutch, European and global market despite the lack of extensive knowledge on the health risks of the use of nanomaterials. In order to gather more insight in the possible exposure of consumers to nanomaterials in consumer products, several product inventories of nano-consumer products have been made in the past. However, crucial information for exposure assessment is missing in these inventories. In the present report, an attempt was made to gather this information. A set of market reports describing global market values for the various consumer products containing nanomaterials were purchased. From these reports a ranking of nanomaterials used in consumer products has been made based on relative presence on the global nano-market, at present and in the near future (2010-2015). Although more specific information is provided in these reports, still information is missing for a detailed exposure assessment. Therefore, a panel of RIVM nano- and exposure experts has been consulted to identify and estimate the most relevant exposure characteristics within the different product categories. These expert estimations were combined with the ranking of nanomaterials in consumer products based on market value in order to identify product categories with a high priority for future exposure studies. Product categories with a high priority for future exposure studies were: sun cosmetics, coatings and adhesives (do-it-yourself (DIY) products).

Key words:

nanomaterials, consumer products, expert evaluation, market reports, external exposure

Contents

Summary	5
1 Introduction	6
2 Update of product inventory based on new public data	8
2.1 Summary of the previous product inventory	8
2.2 Recent trends in available data	8
2.2.1 WWI database	8
2.2.2 Nanotech Product Directory	10
2.3 Limitations of product inventories	11
3 Summary of purchased market reports	12
3.1 Selection of applicable market reports	12
3.2 Information provided in the market reports	14
3.2.1 BCC Research report (BCC, 2008)	14
3.2.2 Nanoposts report (Nanoposts, 2008a)	14
3.2.3 Technology Transfer Centre report (Nanoposts, 2008b)	14
3.2.4 Trimark Publication (Trimark Publication, 2006)	15
3.3 General remarks and comparison of data in various market reports	15
4 Market value analysis	16
4.1 Approach of the market value analysis	16
4.2 Classification of products into (sub) categories	16
4.3 Ranking of categories on relative presence on the market	17
4.4 Ranking of products on relative contribution of market value	19
4.5 Chemical entity of nanomaterials in consumer products	20
4.6 Estimated amount of the nanomaterials on the consumer market	23
4.7 Limitations with respect to market value analysis	30
5 Expert consultation	31
5.1 Approach of expert consultation	31
5.2 Characteristics of the possible exposure	31
5.3 Categorising and ranking of products	33
5.4 Limitations and uncertainties with respect to exposure characteristics	37
5.4.1 Nanomaterial in consumer product	37
5.4.2 Application	38
5.4.3 Exposure route	38
5.5 Discussion of expert consultation	39
6 Conclusions and discussion	40
References	42
Appendix I	43

Summary

The aim of the present research was to identify consumer products containing nanomaterials with a high priority for future exposure studies. There are already several consumer products available on the Dutch, European and global market that contain nanomaterials despite the limited knowledge on the health risks of using these products. The number of applications is still growing, therefore the investigation also included products that are still in the developmental phase and that are expected to become available on the market in the future.

The health risks of consumer products containing nanomaterials are determined by a combination of the possible hazards of the nanomaterials used in these products and the possible exposure to these nanomaterials. Within the exposure assessment, a distinction can be made between external and internal exposure. This report is focused on identification of external exposure, i.e. the total ingested, dermally applied or inhaled dose of nanomaterials due to the use of consumer products.

First inventories that were made in the past were updated with more recent publicly available data. These data are focused on products that are claimed or advertised to contain nanomaterials. However, there is no verification for these claims. Based on the analysis of the product inventories in 2007 and the recent update described in this report, consumer products containing silver are becoming more and more abundant. Within the different product inventories, the product categories “Home furnishing & household products” and “Health and Fitness” contain the majority of the products. These categories include the subcategories cleaning products, coatings, cosmetics, clothing, personal care, sporting goods, sunscreen and water- and air-filtration.

In addition, information available in market reports was used to gather information on the global market share of products containing nanomaterials. Based on the analysis of the market reports, the consumer product group of coatings and adhesives contains the highest production (in tonnes) of nanomaterials, both at present and in the near future (2010-2015). The nanomaterials in this group are polymers in aqueous polymer suspension for the applications in e.g. exterior paints, coatings and adhesives and in the finishing of textiles and leathers. Other product groups that are ranked high on basis of the estimated production of nanomaterials (both now and in the near future) are food packaging materials, catalytic converters, automotive components and sun cosmetics.

The information from product inventories and market reports was not sufficient to perform a detailed exposure assessment that is needed for the identification of consumer products with a high priority for future exposure studies. Therefore, an RIVM expert panel was created to identify the most important exposure characteristics and categorise consumer products in possible high, medium and low exposure. According to most experts, personal care products and cosmetics (including sun cosmetics, oral hygiene products, supplements and health products) are expected to lead to high possible exposure. Other products like fuel for motor vehicles (after combustion) and do it yourself (DIY) coatings, adhesives and cleaning products are also expected to lead to high potential exposure by most experts.

After combination of the three different approaches, product groups with high priority for future exposure studies were identified. Sun cosmetics, DIY coatings and adhesives appeared to be important in all three analyses. Personal care products and cleaning products were judged important in the product inventories and in the expert consultation (for the subcategory sun cosmetics within the category personal care products UV blockers were also ranked high in the market analysis). With respect to the near future, the same product categories are expected to stay important.

1 Introduction

Nanotechnology is a promising technology which enables development and application of many different types of products. It encompasses a wide variety of technologies at the nanoscale including the production of nanoscale materials (nanomaterials). Nanomaterials are developed and used because they have new specific physico-chemical properties compared to the conventional material of the same chemical composition. These properties include changes in pharmacokinetic and targeting properties, optical properties, catalytic properties, porosity, electromagnetic properties, mechanical properties (stiffness and elasticity) and material and structural surface properties such as strength, weight reduction and increased stability. All these characteristics can lead to an improved functionality of the used material. Apart from the improved functionalities in the applications, nanomaterials may also be important for environmental sustainability. Furthermore, the development of new nanomaterials and applications are expected to stimulate the economy by innovation, competitiveness and employment.

Nanomaterials are used in a wide variety of applications including medical and pharmaceutical, agricultural and material applications (coatings, construction, textiles etc.), applications in information and communication technology, military technology energy, chemistry, transport, food and consumer products.

The present report is focused on the use of nanomaterials in consumer products. These products meet the following criteria:

- The product is a non-food product.
- The product is finished, meaning that no raw materials or semi-finished products are taken into account.
- The product has been claimed to contain nanomaterials. This excludes products that are created by nanotechnology, but do not contain nanomaterials themselves.
- The product is currently on the market (or expected to reach the market within a few years).

Although there is still only limited knowledge on the health risks of using nanomaterials in various applications, there are already several consumer products containing nanomaterials available on the global, European and Dutch market. In the past few years, several inventories on the use of nanomaterials in consumer products have already been made by RIVM (Dekkers et al, 2007a, b, Wijnhoven et al, 2009). These reports were mainly focused on the availability of nanomaterial-containing products for the Dutch (European) consumer, and gave an indication of the possible exposure of consumers to nanomaterials from the use of consumer products. However, only publicly available data in literature and on websites were used for these inventories, and the data were mostly based on claims of the product manufacturers. No detailed exposure assessment was performed and no ranking of products was made in terms of likelihood of external exposure because of the lack of crucial information.

The potential health risks of consumer products containing nanomaterials depend on the possible hazards of the nanomaterials in these products and the possible exposure to these nanomaterials. As for conventional chemicals, the risk assessment of nanomaterials consists of hazard characterization (including hazard identification and dose response assessment) and exposure assessment (including external exposure assessment and toxicokinetics). The base elements of risk assessment are schematically depicted in Figure 1.1. After the assessment of the (external) exposure (the total ingested, dermally applied or inhaled dose of nanomaterials), information on toxicokinetics of the nanomaterials (the absorption, distribution, metabolism and excretions) determines the internal dose (the dose of nanomaterials that reaches the systemic circulation, organs and tissues of man). This report is focused

on the assessment of the external exposure, i.e. the total ingested, dermally applied or inhaled dose of nanomaterials due to the use of consumer products.

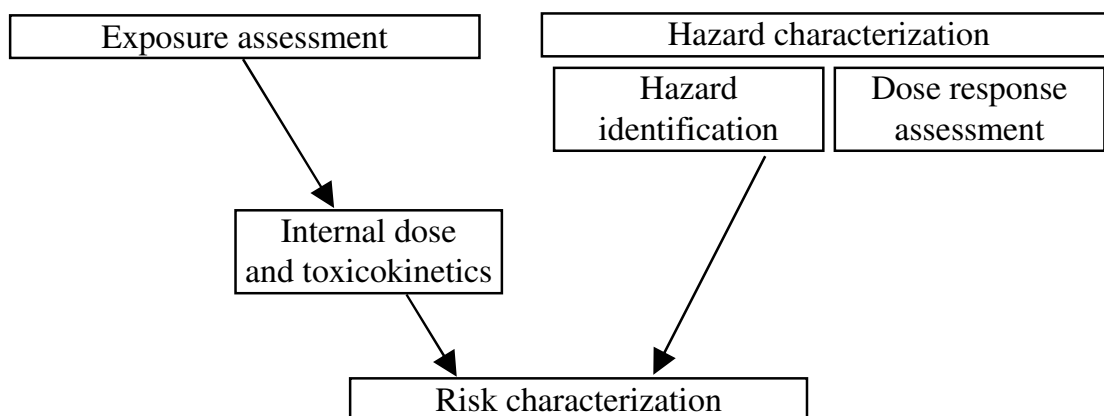


Figure 1.1 Base elements of risk assessment

Within the framework of research question 9.1.6 (project number V/340370): “Health risks of the application of nanotechnology in consumer products”, the Dutch Food and Consumer Product Safety Authority asked RIVM to write the present report with the aim to answer the following research question (9.1.6a):

Which consumer products containing nanomaterials (including products that are still in the developmental phase and not yet available on the market) are relevant for future research on exposure to nanomaterials?

For this, the earlier inventories are updated with more recent public data (chapter 2). In addition, a summary is given on the information of several selected and purchased market reports (chapter 3). In chapter 4, a ranking of consumer product (categorie)s is described based on estimated marked share in the market reports. Together with the description of relevant exposure characteristics in chapter 5, a final ranking of consumer products relevant for future research on exposure has been made. Chapter 6 contains, apart from this ranking, some general conclusions and discussion.

2 Update of product inventory based on new public data

2.1 Summary of the previous product inventory

In a previous study of the RIVM in 2007, an inventory was made of consumer products expected to contain nanomaterials that were probably available on the Dutch market (Dekkers et al, 2007a). In this inventory, 143 nanomaterial containing consumer products were identified. The following data sources were used:

- internet sites of Dutch manufacturers and distributors
- contact with Dutch manufacturers (by telephone)
- internet sites of foreign manufacturers and distributors
- the Woodrow Wilson database of consumer product (US)
- the Nanotech Product Directory (www.nanoshop.com)
- information from manufacturers present at the Nanosolutions 2007 symposium in Köln

Only products from EU manufacturers or well known multi-nationals were included in the database. Most of these products (approximately 120) were expected to be available on the Dutch market. The different products were categorized into several product categories and subcategories, similar to the categories used in the Woodrow Wilson International Centre for Scholars database. Most of the products available on the Dutch market belong to the main category “Home furnishing & household products”, with the majority of consumer products in the subcategories “Cleaning products” and “Coatings”. Most of the products consist of a liquid matrix, sometimes contained within a spray can or in a bottle with a spray head. Silver, carbon and silica seemed to be the most widely used nanomaterials within consumer products. However, since information about the chemical composition of nanoparticles was only obtained for a few products, no firm conclusion with respect to most widely used nanomaterials in consumer products could be made at that time.

2.2 Recent trends in available data

2.2.1 WWI database

In the past year, the number of available consumer products containing nanomaterials has grown. To get an impression of new developments and changes in the available products on the market, an analysis of the Woodrow Wilson database on August 21 2008 (containing 803 products), was compared with an analysis of the database on November 26, 2006 (containing 356 products) (WWI database available on www.nanotechproject.org). In Figure 2.1, the trend in number of food and consumer products on the market is further depicted in detail.

At both time points, the product category Health and Fitness contains the majority of the products. This category includes the subcategories cosmetics, textiles and shoes, personal care, sporting goods, sunscreen and filtration.

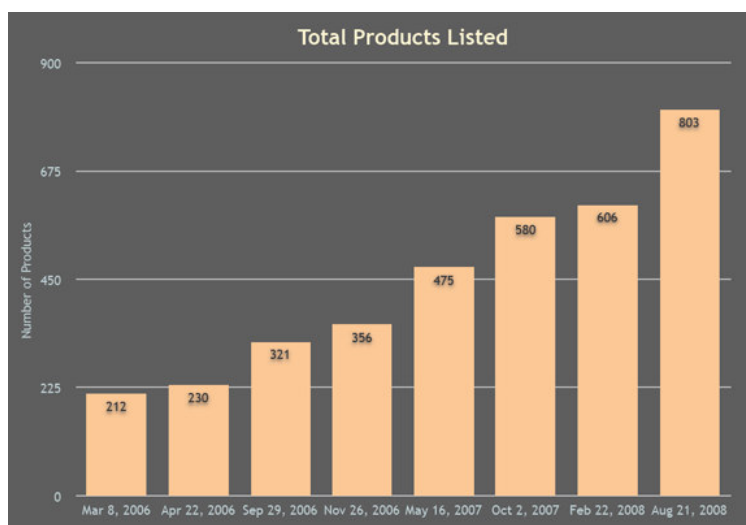


Figure 2.1 Number of total products listed, by date of inventory update (adopted from Woodrow Wilson database available on www.nanotechproject.org)

Next to the increased number of consumer products, the following trends were observed within the WWI database:

- The percentage of products within the category food and beverages is higher in 2008 (10% or 80 products) than in 2006 (8% or 29 products). It should be noted that this report focuses on non-food consumer products, which means that food and beverages are excluded.
- The percentage of products within the category electronics and computers is lower in 2008 (7% or 56 products) than in 2006 (10% or 35 products)
- The percentage of products within the sub-category personal care is higher in 2008 (30% or 153 products) than in 2006 (19% or 43 products)
- The percentage of products within the sub-categories cosmetics and clothing is lower in 2008 (25% or 126 products and 23% or 115 products, respectively) than in 2006 (28% or 64 products and 27% or 62 products respectively)
- The percentage of products containing silver is higher in 2008 (29% or 235 products) than in 2006 (13% or 47 products).

In some cases, companies changed product information and removed the earlier made nano claims. For instance the company Sharper Image was making claims in 2006 that the FresherLonger™ Miracle Food Storage contained silver particles that made the product antibacterial. By 2007, those claims had been removed but according to the company, the product has not changed.

With respect the nanomaterial used within consumer products, silver is by far the mostly used nanomaterial according to the WWI database. In 2008, a review report has been written on the health risks of nano-silver when exposed via food, consumer products and medical products, and/ or via the environment. Within this review specific products containing nano-silver have been listed (Wijnhoven et al, 2009). At that time, in total 153 consumer products and 38 medical products containing nano-silver were found (the WWI update of February 2008 has been used for this). According to the most recent update of the WWI database of August 2008, this number had further increased to 235 products as is clearly shown in Figure 2.2.

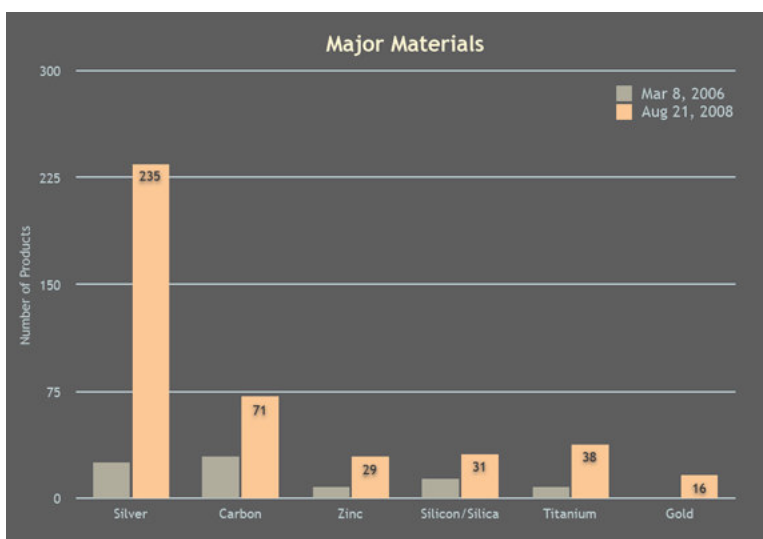


Figure 2.2 Number of products associated with specific materials (adopted from Woodrow Wilson database available on www.nanotechproject.org).

In addition, the WWI database has recently published data on nano-silver concentrations in various products such as food containers, food supplements, socks and creams. However, the number of products with known concentrations is very low; only 36 out of 244 products (varying from dietary supplements to cosmetics and wound dressings) have known nano-Ag concentrations. These concentrations of nano-silver range between <6 and 10000 ppm. The highest concentrations were found in so-called 'nano-silver master batches' that are not end-products itself, but are used in consumer products (<http://www.nanotechproject.org/inventories/silver/>). Apart from the concentration, also migration and leaching data are very important for assessment of exposure and risk of nano-silver in consumer products (see also chapter 5).

2.2.2 Nanotech Product Directory

In addition to the WWI database, the Nanotech Product Directory (www.nanoshop.com) (containing 433 consumer as well as industrial products and services) was consulted again to investigate how many and what nano-containing consumer products had been added and removed from this database, when compared to the list of the products found in 2006. In 2006 18 consumer products from EU manufacturers were identified. In 2008, about 10 additional consumer products of EU manufacturers could be identified within this directory. Seven coatings and surface treatment products, one skin care product, one cooking utensil and one product within the category miscellaneous were added to the directory. No products of EU manufacturers were removed from it.

The other data sources were not consulted again. However, it is likely that similar trends will be observed within the databases. Also for the Dutch market such an increase can be expected. Based on this analysis, it seems that personal care products and consumer products containing silver are becoming more abundant.

2.3 Limitations of product inventories

Within the various product inventories specific products and brands containing nanomaterials are identified. These inventories give an idea of the amount of products containing nanomaterials on the market (e.g. how many sunscreen products with nanomaterials are available on the market). However, they do not mention the production quantity, value, chemical entity and concentration of the specific nanomaterials.

The most important limitation of the public inventories is that the information provided in these inventories is based on claims and advertisements of manufacturers. It is not verified if they actually do contain nanomaterials, and no measurements were conducted on these products. Furthermore, the inventories may not be complete. Some products that contain nanomaterials might not be included. At present there is no legal obligation to inform consumers or label products that contain nanomaterials. This may change in the future as the Dutch Parliament and the European Parliament are taking initiatives for specific notification and/ or labelling of “nano-products”.

3 Summary of purchased market reports

For our current research question on ranking of consumer products for further exposure research, information on the market share of consumer products containing nanomaterials compared to consumer products without nanomaterials is needed. To obtain such information, several commercially available market reports with information on the commercial potential of nanotechnology within consumer applications were purchased.

3.1 Selection of applicable market reports

A selection of the most recent and relevant market reports was made for further analysis. In total 16 different market reports published between 2005 and 2008 have been evaluated based on the summaries, descriptions and tables of contents of the reports available on the internet.

The following criteria (in random order) were used for the selection:

1. The data should be specified on product level and not on application or sector level
2. The information should concern the European market instead of the global market
3. The report should concern the use of nanotechnology in consumer products instead of nanotechnology in general
4. The information should be available on the use of nanomaterials in consumer products instead of the use of nanotechnology in the production of consumer products
5. The report should contain recent data

As the purchase of the reports was based on the titles as presented in the contents, the titles of the chapters, tables and figures in the report should indicate the applicability of the data for our research question.

In Table 3.1, the four selected market reports are listed. For each report, a short evaluation of the different abovementioned criteria is given.

Table 3.1 Selected market reports (including their evaluation of the selection criteria)

Publishing date	Title	Author/publisher
May 2008	Nanotechnology: A Realistic Market Assessment	BCC Research
Evaluation of selection criteria: 1. For some products data seem to be available, but not for all. Most data is available per application area. 2. Global market. 3. Nanotechnology in general. 4. It is not clear if data concern the use of nanotechnology or the use of nanomaterials. 5. This is the most recent market report. According to the contents, especially chapter 2 and 4 seem to be relevant (and may be purchased separately)		
Dec 2007 Jan 2008	Nanotechnologies for Consumer Products The Impact of Nanotechnology on the Consumer Goods Market to 2015	Nanoposts.com Nanoposts
Evaluation of selection criteria: 1. Data seems to be available on product level. 2. Global market. 3. Nanotechnology in consumer products. 4. Data seems to concern the use of nanomaterials. 5. Reasonably recent.		
Aug 2007	Research and Commercialisation in Nanotechnology in Europe	Technology Transfer Centre
Evaluation of selection criteria: 1. All data is specified per key applications. 2. European market. 3. Nanotechnology in general. 4. Data seems to concern the use of nanomaterials. 5. Reasonably recent.		
Oct 2006	Global Value of Nano Inputs by Type of Consumer Products, 2005-2012	TriMark Publications
Evaluation of selection criteria: 1. It is not clear if the data is specified per sector, application area or product. 2 Global market. 3. Nanotechnology in consumer products (although we have some doubts with respect to the definition of consumer product, since the report also includes medicines and biotechnology). 4. It is not clear if data concern the use of nanotechnology or the use of nanomaterials. 5. Rather old.		

3.2 Information provided in the market reports

In the next paragraphs, the useful information from the various reports to identify relevant consumer products containing nanomaterials is described. It should be noted that the information published in the market reports is confidential and cannot be shared with other parties without written permission of the publishers. Therefore, all information available including that of the market reports is used to estimate a relative ranking instead of numerical information of market values (see chapter 4).

3.2.1 BCC Research report (BCC, 2008)

- Overview of the global nanotechnology consumption by end-user segment (including consumer products, environmental remediation, electronics, energy, etc) in 2007.
- Overview of the expected growth rate over the next 5 years of the different end-user markets (including consumer products, biomedical applications and electronics).
- Overview of patents by type of technology (materials)
- Overview of most important commercial nanoparticles applications
- For some applications (like sunscreen) the market share of nanoparticles containing products is estimated (e.g. sunscreen containing nanoparticulate TiO₂ and ZnO)
- For all nanoparticles application the global market, consumption or sales is estimated, but this is not expressed relative to the total market, consumption or sales (including applications without nanoparticles).
- Overview of most important companies in the a) nanomaterial market, b) nanotools market, and c) nanodevices market.

3.2.2 Nanoposts report (Nanoposts, 2008a)

- Overview of most important companies in the consumer good market
- Overview of the relative importance of the different sub-sectors (e.g. house hold care, packaging, personal care, leisure equipment, etc.)
- For sub-sector the revenue and revenue forecast of the implementation market is estimated (xx million), but this is not expressed relative to the total market (including applications without nanotechnology).
- Description of the use of nanomaterials (particles, composites, capsules, fullerenes, CNT, coatings) in the different sectors, including brand owners, suppliers and application manufactures, market (revenue) and sometimes applications.
- Overview of the most important technology providers in each market area (cosmetics and toiletries, sunscreen, dental products), including detailed descriptions of all technology providers.

3.2.3 Technology Transfer Centre report (Nanoposts, 2008b)

- Overview of the relative importance of the sectors (e.g. ITC and electronics, chemicals, life sciences and healthcare, auto and transport, etc.) in Europe (and Asia-Pacific, North America and Worldwide)
- Description of the use of nanomaterials (particles, composites, capsules, fullerenes, CNT, coatings, nanoporous materials, quantum dots, nanofibres and nanowires) in the different sectors, including brand owners, suppliers and application manufactures, market (revenue) and sometimes applications.

- Overview of the governmental bodies, research centres, networks, universities, and companies in each EU country.

3.2.4 Trimark Publication (Trimark Publication, 2006)

- Global value of nano inputs by type of consumer products (passenger cars, electrical goods, food and beverages, household chemical, and other consumer products –photographic equipment and film, textiles and apparel, personal care products, sporting goods and consumer optical products-).

3.3 General remarks and comparison of data in various market reports

In general, the global market value for nanomaterials used in consumer products is estimated to increase with more than 50% (from present to the near future). However, due to the current economic crisis and reduced sales (in e.g. cars, building materials and electronics), the estimation for the near future might be too optimistic.

Differences exist between the information on the global market values for nanomaterials used in consumer products that is provided in the various market reports. Information from the BCC report is for instance comparable with that provided in the TriMark Publications market report (TriMark Publications 2006). Remarkably, the estimations made by both reports of Nanoposts.com were more than twice as high as the BCC and TriMark estimations (Nanoposts.com 2008a, b). The reason for this discrepancy is not known.

It should be realized that certain types of nanomaterials and nanodevices that fit the nano and consumer product description, for instance carbon black (used in ink and pigments, reinforcement of rubber), activated carbon (in filtration) and photographic silver, were already on the market long before nanotechnology existed. Some market reports exclude these products from their analysis since they only focus on products based on new (nano-) technology. This does not mean that these materials don't have a high market value or that they are not important.

4 Market value analysis

4.1 Approach of the market value analysis

To identify consumer products with a high priority for future exposure studies, information is needed on: a) how many consumer products containing nanomaterials are on the market, b) the amount and type of nanomaterials in these products, and c) how many consumers use products containing nanomaterials. This information can not directly be extracted from the market reports.

Therefore, a multi step approach on the data available in the different purchased market reports (BCC, 2008; Nanoposts 2008a, 2008b; Trimark Publication, 2006) has been carried out in order to indirectly gather as much information as possible. Although in the selection criteria there was a preference for the European market, the analysis is done for the global market, since this is the focus of the majority (3 out of 4) of the analysed reports.

The following steps have been carried out (step 1 to 4 is described in this chapter in the paragraphs below):

1. Classification of products containing nanomaterials in product (sub)categories
2. Ranking of product (sub)categories and consumer products based on the market value of the nanomaterials used in the products
3. Identification of the chemical entity of the nanomaterials in consumer products and ranking of the nanomaterials based on the market value
4. Calculation of the total amount of nanomaterials used in the consumer market after correction of the value of the various nanomaterials used and ranking of the products

After this analysis of the market report results, sequential steps for a definite priority list of consumer products are:

5. Identification of exposure characteristics as well as the possible exposure by different experts (described in chapter 5)
6. Definition of a priority list of relevant consumer products containing nanomaterials for future research on exposure (described in chapter 6)

4.2 Classification of products into (sub) categories

For comparison of various products, a classification into (sub) categories has to be made. These (sub) categories in which consumer products are classified appear to be different in the various market reports and public available consumer product inventories such as the Woodrow Wilson database (www.nanotechproject.org).

To compare the different sources of information, we use the classification as described in Table 4.1, based on the category classification previously used in Dekkers et al (2007b). Within this categorisation we cannot exclude the possibility that some overlap exists between categories, because some products can be categorised under more than 1 category. For instance exterior paints is categorised under miscellaneous (coatings), but it also belongs to the group of home improvement (coatings) products.

Table 4.1 The consumer categories and subcategories in which the consumer products containing nanomaterials can be categorized

Product category	Subcategory
electronics and computer	computer hardware display recording media energy related (battery) electronic parts lighting ink and paper
household products and home improvement	packaging cleaning products coatings
personal care and cosmetics	sun cosmetics over the counter health products oral hygiene
motor vehicles	catalytic converter interior fuel coatings lighting
sporting goods	equipment
textiles and shoes	textile coating coatings professional clothing other textiles
filtration, purification neutralisation and sanitisation	water filtration and purification air filtration and purification
miscellaneous	coatings (and adhesives) isolation material

4.3 Ranking of categories on relative presence on the market

The products as described in the market reports are incorporated in this classification and subsequently ranked on the relative market value (in %) of the nanomaterials used in the products of these (sub) categories (at present and in the near future (2010-2015); Table 4.2).

The absolute market values are presented in the various market reports we have consulted. However, because this is confidential information, a relative market value is calculated for every product category and presented in different categories in the table below. For our aim of ranking product categories, a relative number presented in a relative market value category is sufficient.

Table 4.2 The relative market value (in %) of relevant consumer categories and subcategories based on the estimated global market of nanomaterials used in these (sub) categories at present and in the future (2010-2015).

Product category	Relative market value category (%)		Subcategory	Relative market value category (%)	
	present	future		present	future
motor vehicles	>50	40-50	catalytic converter	>50	30-40
			interior	1-10	1-10
			fuel	<1	<1
			coatings	<1	<1
			lighting	<1	<1
electronics and computer	10-20	30-40	computer hardware	1-10	1-10
			display	1-10	10-20
			recording media	1-10	<1
			energy related (battery)	<1	1-10
			electronic parts	<1	<1
			lighting	<1	1-10
miscellaneous	10-20	10-20	ink and paper	<i>not reported</i>	
			coatings (and adhesives)	10-20	10-20
household products and home improvement	1-10	1-10	isolation material	<1	1-10
			packaging	1-10	1-10
			cleaning products	1-10	1-10
personal care and cosmetics	1-10	1-10	coatings	<1	<1
			sun cosmetics	1-10	1-10
			over the counter health products	<1	<1
sporting goods	<1	1-10	oral hygiene	<1	<1
			equipment	<1	1-10
textiles and shoes	<1	<1	textile coating	<1	<1
			coatings	<1	<1
			professional clothing	<1	<1
			other textiles	<1	<1
filtration, purification neutralisation and sanitisation	<1	<1	water filtration and purification	<1	<1
			air filtration and purification	<1	<1

From this table it is clear that the use of nanomaterials in the consumer category of motor vehicles was by far market leader, based on estimated market value at present. It is estimated that in the near future, the consumer category of electronics and computer will (almost) reach the level of motor vehicles. Please note that the estimated market value is relative. For motor vehicles, where it is indicated in the report that the absolute market value remains constant, the relative market value decreases.

The consumer category “miscellaneous” represents the polymers used in isolation materials (silica aerogels in e.g. construction) and coatings and adhesives, for instance aqueous polymer suspension. These suspensions are used in exterior paints, coatings and adhesives, finishing of papers, textiles and leather.

4.4 Ranking of products on relative contribution of market value

As can be observed from Table 4.2, the (sub) categories consist of various consumer products containing nanomaterials. In this paragraph, the individual consumer products within these categories are identified and the relative contribution of these products to the total value of nanomaterials in consumer products is estimated. Therefore, a ranking in categories is made based on the relative contribution (in %) of the estimated global market value for nanomaterials used in the products (at present and in the near future (2010-2015)) (Table 4.3). Again, the absolute numbers of the market values are presented in the consulted market reports, but because of the confidentiality of the data, only relative numbers are presented in categories below. The products are also ranked within one category, which means that for instance the hard disk media in the category of 1-10% has a higher relative market value than the automotive components within the same category.

Table 4.3 Ranking of consumer products containing nanomaterials. The products are ranked based on their relative market value (in %) of the estimated global market for nanomaterials in consumer products at present and in the future (2010-2015).

Product group	Relative market value category (%) at present	Product group	Relative market value category (%) in future
catalytic converters	>50	catalytic converters	40-50
coatings and adhesives	10-20	flat panel display	10-20
hard disk media	1-10	coatings and adhesives	10-20
flat panel display	1-10	hard disk media	1-10
food packaging	1-10	nanotubes - electronics	1-10
automotive components	1-10	food packaging	1-10
UV absorbers in cosmetics	0.1-1	lithium ion batteries	1-10
magnetic recording media	0.1-1	insulation	1-10
insulation	0.1-1	UV absorbers in cosmetics	1-10
photocatalytic coatings	0.1-1	automotive components	1-10
anti-scratch/stick - household products	0.1-1	light emitting diodes	1-10
cladding of optical fibres	0.1-1	sporting goods	1-10
sporting goods	0.1-1	photocatalytic coatings	0.1-1
wire and cable sheathing	0.1-1	transparent electrodes	0.1-1
eyeglass/lens coating	0.1-1	anti-scratch/stick - household products	0.1-1
antimicrobial dressings	0.1-1	wire and cable sheathing	0.1-1
xenon lighting	<0.1	antimicrobial dressings	0.1-1
filtration system	<0.1	magnetic recording media	0.1-1
optical recording media	<0.1	diesel fuel additives	0.1-1

Product group	Relative market value category (%) at present	Product group	Relative market value category (%) in future
ferrofluids	<0.1	nanotubes – textiles	0.1-1
diesel fuel additives	<0.1	eyeglass/lens coating	0.1-1
fabric treatment	<0.1	cladding of optical fibres	0.1-1
air purification systems	<0.1	filtration system	<0.1
transparent electrodes	0 ¹	anti-scratch/stick - motor vehicles	<0.1
toothpaste	0	nanocomposites	<0.1
nanotubes – textiles	0	xenon lighting	<0.1
nanotubes - electronics	0	ferrofluids	<0.1
nanocomposites	0	fabric treatment	<0.1
lithium ion batteries	0	optical recording media	<0.1
light emitting diodes	0	algae preventers	<0.1
anti-scratch/stick - motor vehicles	0	air purification systems	<0.1
algae preventers	0	toothpaste	n.r.
UV absorbers – textiles	n.r. ²	UV absorbers – textiles	n.r.
UV absorbers - motor vehicles	n.r.	UV absorbers - motor vehicles	n.r.
UV absorbers - household products	n.r.	UV absorbers - household products	n.r.
surface disinfectant ³	n.r.	surface disinfectant	n.r.
inks and pigments ⁴	n.r.	inks and pigments ¹	n.r.

¹ 0 because these products were not on the market in 2008 yet

² n.r. = not reported

³ for surface disinfectant, a total market value is reported but not the % used in consumer products

⁴ inks and pigments were not included in the market report (carbon black)

Table 4.3 shows that in both the estimations for at present and in the near future, the relative contribution is highest for the subcategory catalytic converters of the product category motor vehicles (with palladium, rhodium, alumina and platinum nano-film as nanomaterials). A decrease in relative market value is seen for this category from >50% (at present) to 40-50% (in the future). As stated above, in a growing market a relative decrease does not necessarily mean a decrease in absolute value as it may be the result of an increase in other areas. Furthermore, the total market of consumer products containing nanomaterials is dominated by 6-12 product groups that have a significant contribution, all other product groups only represent < 1% of the market.

4.5 Chemical entity of nanomaterials in consumer products

For hazard identification purposes, a prerequisite will be the determination of the chemical entity of the nanomaterials used in consumer products (Hansen et al., 2008). For this, a coupling of product group, product category and subcategory with the corresponding chemical entity of the nanomaterials in the consumer product is needed. In Table 4.4 the chemical entity of nanomaterials is linked to the consumer product group, product category and subcategory, based on the market reports. However, it is not

excluded that nanoparticles of a specific chemical entity are used in more of the mentioned product categories. For instance, it is known from the product inventories and our recent published review (Wijnhoven et al, 2009) that silver nanoparticles are used in more different consumer products than indicated in the table below, for instance food packaging products, cosmetics, computer hardware, cooking utensils etc. However, in this table, only the consumer products described in the market reports are included.

Table 4.4 Alphabetical list of the chemical entities of nanomaterials used in consumer products. Per chemical entity, the corresponding consumer group, category and subcategory is given.

Chemical entity	Product group	Subcategory	Product category
alumina	catalytic converters	catalytic converter	motor vehicles
alumina	xenon lighting	lighting	motor vehicles
alumina	filtration system	water filtration and purification	filtration and purification
alumina (thin film)	optical recording media	recording media	electronics and computer
carbon black	inks and pigments	ink and paper	electronics and computer
carbon nanotubes (CNT)	nanotubes - development	display	electronics and computer
CNT	nanotubes - development	other textiles	textiles and shoes
CNT	transparent electrodes	display	electronics and computer
CNT	transparent electrodes	energy related	electronics and computer
CNT	nanotubes - development	energy related	electronics and computer
CeO	diesel fuel additives	fuel	motor vehicles
chromium, cobalt and carbon	hard disk media	computer hardware	electronics and computer
composites (inc CNT)	sporting goods	equipment	sporting goods
HAP (hydroxyapatite)	toothpaste	oral hygiene	personal care and cosmetics
iron oxide and alumina	magnetic recording media	recording media	electronics and computer
iron oxide nanoparticles	ferrofluids	electronic parts	electronics and computer
iron oxide nanoparticles	ferrofluids	computer hardware	electronics and computer
lanthanum nanoparticles	algae preventers	water filtration and purification	filtration and purification
lithium nanoparticles	lithium ion batteries	energy related	electronics and computer
nano polymer thin film coating	eyeglass/lens coating	cleaning products	household products / home improvement
nanoclay	food packaging	packaging	household products / home improvement

Chemical entity	Product group	Subcategory	Product category
nanoclay	wire and cable sheathing	electronic parts	electronics and computer
nanoclay (cotton)	nanocomposites-development	professional clothing	textiles and shoes
nanoclay, polymer, carbon	automotive components	interior	motor vehicles
nanophosphor (quantum dots)	light emitting diodes	lighting	electronics and computer
oil nanospheres	surface disinfectant	coatings	miscellaneous
palladium	catalytic converters	catalytic converter	motor vehicles
platinum	catalytic converters	catalytic converter	motor vehicles
polymer	coatings and adhesives	coatings and adhesives	miscellaneous
polymer	flat panel display	display	electronics and computer
polymer	fabric treatment	textile coating	textiles and shoes
polyurethane/alumina nanocomposites	anti-scratch/stick	cleaning products	household products / home improvement
quantum dots	light emitting diodes	lighting	electronics and computer
rhodium	catalytic converters	catalytic converter	motor vehicles
silica aerogel	insulation	isolation materials	miscellaneous
silica based nanofilm	cladding of optical fibres	electronic parts	electronics and computer
silver nanoparticles	antimicrobial dressings	over the counter health products	personal care and cosmetics
TiO ₂	air purification systems	air filtration and purification	filtration and purification
TiO ₂	UV absorbers	coatings	household products / home improvement
TiO ₂	UV absorbers	coatings	motor vehicles
TiO ₂	UV absorbers	coatings	textiles and shoes
TiO ₂ thin films	photocatalytic coatings	cleaning products	household products / home improvement
TiO ₂ , ZnO	UV absorbers	sun cosmetics	personal care and cosmetics
various materials ¹	anti-scratch/stick	cleaning products	household products / home improvement

¹ Various materials including alumina, silica, titanium and zirconium

Subsequently, the various chemical entities of Table 4.4 are ranked, based on their relative market value (in %) of the estimated global market for nanomaterials in consumer products at present and in the near future (Table 4.5). When possible, comparable materials originated from different consumer products are added. For consumer products in which different chemical entities are used of which the ratio in the product is not known, the combination of the various chemical entities is given. Again, also a ranking is made within one category, meaning that for instance within the category of 1-10%, rhodium has a higher relative market value than silica.

Table 4.5 Ranking of the chemical entity of the nanomaterials used in consumer products. The chemical entities are ranked based on their relative market value (in %) of the estimated global market for nanomaterials in consumer products at present and in the future (2010-2015).

Chemical entity	Relative market value category (%) at present	Chemical entity	Relative market value category (%) in the future
platinum	30-40	platinum	20-30
palladium	20-30	polymer	20-30
polymer	10-20	palladium	10-20
chromium, cobalt and carbon ¹	1-10	chromium, cobalt and carbon ¹	1-10
rhodium	1-10	carbon nanotubes (CNT)	1-10
nanoclay	1-10	nanoclay	1-10
titanium dioxide (TiO ₂) ²	1-10	rhodium	1-10
nanoclay, polymer, carbon ³	1-10	lithium nanoparticles	1-10
silica	1-10	titanium dioxide (TiO ₂) ²	1-10
iron oxide and alumina	0.1-1	silica	1-10
alumina (thin film)	0.1-1	nanoclay, polymer, carbon ³	1-10
polyurethane/alumina nanocomposites	0.1-1	nanophosphor	0.1-1
various materials ⁴	0.1-1	quantum dots	0.1-1
carbon nanotubes (CNT)	0.1-1	alumina (thin film)	0.1-1
silver nanoparticles	0.1-1	polyurethane/alumina nanocomposites	0.1-1
iron oxide nanoparticles	<0.1	silver nanoparticles	0.1-1
cerium oxide (CeO)	<0.1	various materials ⁴	0.1-1
hydroxyapatite (HAP)	0 ⁵	iron oxide and alumina	0.1-1
lanthanum nanoparticles	0	cerium oxide (CeO)	0.1-1
lithium nanoparticles	0	iron oxide nanoparticles	<0.1
nanophosphor	0	lanthanum nanoparticles	<0.1
oil nanospheres	0	oil nanospheres	<0.1
quantum dots	0	hydroxyapatite (HAP)	n.r.
carbon black ⁶	n.r. ⁷	carbon black ⁶	n.r.

¹ These materials are used in hard disks (percentage unknown)

² This group also contains zinc oxide (ZnO) containing sunscreen (percentage unknown)

³ These materials are used as interior for the automotive industry (percentage unknown)

⁴ Various materials including alumina, silica, titanium and zirconium

⁵ 0 because these products were not on the market in 2008 yet

⁶ Inks and pigments were not included in the market report (carbon black)

⁷ n.r. = not reported

4.6 Estimated amount of the nanomaterials on the consumer market

It should be noted that the previous tables on relative market values only give estimations on the economic importance of nanomaterials, and not on the amount of nanomaterials used in the consumer product market.

For exposure assessment, it will be of utmost importance to identify and rank the nanomaterials based on the amount of nanomaterial that is used on the total global consumer market. To do so, the estimated price per nanomaterial is needed. Table 4.6 ranks the estimated price of the nanomaterials used in consumer products (in different price categories). The estimations were obtained from various sources,

the BCC Research market report and Google™ using the intended nanomaterial (e.g. nanoclay, carbon nanotube, quantum dot) and the word “price” (visited March 2009).

Table 4.6 The estimated price per kilogram of the nanomaterials used in consumer products.

Nanomaterial	Price category (\$ per kg)	Reference
quantum dots	>50 000	internet ¹
nanophosphor (quantum dots)	>50 000	internet ¹
rhodium	>50 000	BCC, 2008
platinum	5000 - 50 000	BCC, 2008
silver nanoparticles	5000 - 50 000	BCC, 2008
palladium	5000 - 50 000	BCC, 2008
HAP (hydroxyapatite)	5000 - 50 000	BCC, 2008
polymer	50 – 500	BCC, 2008
iron oxide nanoparticles	50 – 500	BCC, 2008
alumina	50 – 500	BCC, 2008
lithium nanoparticles	50 – 500	BCC, 2008
carbon nanotubes (CNT)	50 – 500	internet ²
composites (incl CNT)	50 – 500	internet ²
chromium, cobalt and carbon	50 – 500	internet ²
various materials including alumina, silica, titanium, zirconium and silicon carbide	50 – 500	BCC, 2008
polyurethane/alumina nanocomposites	50 – 500	BCC, 2008
iron oxide	5 – 50	BCC, 2008
alumina	5 – 50	BCC, 2008 (based on alumina thin film)
alumina (thin film)	5 – 50	BCC, 2008
polymer	5 – 50	BCC, 2008
TiO ₂ , ZnO	5 – 50	BCC, 2008
TiO ₂	5 – 50	BCC, 2008
nano polymer thin film coating	5 – 50	BCC, 2008
TiO ₂ thin films	5 – 50	BCC, 2008
nanoclay, polymer, carbon	5 – 50	Estimated (based on BCC, 2008, internet ^{2,3})
silica based nanofilm	5 – 50	BCC, 2008
silica hydride	5 – 50	Estimated (based on BCC data on silica)
silica aerogel	5 – 50	Estimated (based on BCC data on silica)
nanoclay	5 – 50	internet ³
nanoclay (cotton)	5 – 50	internet ³
alumina	<5	BCC, 2008
CeO	?	unknown ⁴
lanthanum nanoparticles	?	unknown ⁴

¹ Internet: Method slashes quantum dot costs by 80 % : <http://www.physorg.com/news6279.html> (visited March 2009)

² Internet: CheapTubes.com Carbon Nanotubes (CNTs) Pricelist Page: <http://www.cheaptubes.com/cntpricelist.htm?gclid=CMKO16OBm5kCFQpNQwodByOSCw> (visited March 2009)

³ Internet: Sol-Gel Gateway Forum: Price of nanoclay: http://www.solgel.com/sgforum/forum_posts.asp?TID=752 (visited March 2009)

⁴ No information concerning prices per kilo were found for lanthanum and cerium oxide nanoparticles

For some nanomaterials the price per kg was estimated based on information of comparable materials. In the BCC Research report, different estimations for the same material were used when the material was applied in different products. Examples are alumina in xenon lights that are estimated to cost more than alumina in catalytic converters and polymers in electronics that are estimated to cost more than polymers in coatings.

With the information listed in tables 4.4-4.6, the amount of nanomaterials used in the total global consumer market was calculated. The market value of the different products is divided by the price of the nanomaterial used in the product giving an absolute amount of kilograms/ tonnes of nanomaterials. Then a ranking of consumer products was made, based on the amount of nanomaterials used in each consumer product and, again because of the confidentiality of the data, these numbers are expressed in relative numbers divided in categories. One must realise that there are big uncertainties in both the rankings as well as in the price of the nanomaterials resulting in an even more uncertainty in the relative ranking presented in the tables below. However, it still gives a good impression of the (ranking of) products that contain large amounts of nanomaterials (which is sufficient for the aim of the present research).

In Table 4.7 and 4.8, the absolute (tonnes in categories) and relative amount of nanomaterials (% in categories) used in consumer products at present (Table 4.7) and in the future (2010-2015; Table 4.8) is presented.

Based on the information provided in these tables, the consumer product group of coatings and adhesives contains the highest amount of nanomaterials, both at present and in the near future. The nanomaterials in this group are mainly polymers in aqueous polymer suspension for the applications in e.g. exterior paints, coatings and adhesives and in the finishing of textiles and leathers. Other product groups that are ranked high on basis of the amount of nanomaterials is the group of food packaging materials, catalytic converters, automotive components and UV absorbers. No big changes in the ranking are expected in the near future.

Table 4.7 The relative presence of nanomaterials used in consumer products on the global market (%) at present, based on the total amount (tonnes) of nanomaterials used in consumer products.

Product group	Product category	Subcategory	Nanomaterial used in the consumer product		
			Chemical entity	Amount category (tonnes)	Relative presence on the market category (%)
coatings and adhesives	miscellaneous	coatings (and adhesives)	polymer	>10 000	40-50
food packaging	household products / home improvement	packaging	nanoclay	>10 000	10-20
catalytic converters	motor vehicles	catalytic converters	alumina	>10 000	10-20
automotive components	motor vehicles	interior	nanoclay, polymer, carbon	1 000-10 000	1-10
UV absorbers	personal care and cosmetics	sun cosmetics	TiO ₂ , ZnO	1 000-10 000	1-10
insulation	miscellaneous	isolation material	silica aerogel	1 000-10 000	1-10
hard disk media	electronics and computer	computer hardware	chromium, cobalt and carbon	1 000-10 000	1-10
photocatalytic coatings	household products / home improvement	cleaning products	TiO ₂ thin films	1 000-10 000	1-10
magnetic recording media	electronics and computer	recording media	iron oxide	1 000-10 000	1-10
cladding of optical fibres	electronics and computer	electronic parts	silica based nanofilm	1 000-10 000	1-10
wire and cable sheathing	electronics and computer	electronic parts	nanoclay	100-1 000	<1
flat panel display	electronics and computer	display	polymer	100-1 000	<1
anti-scratch/stick	household products / home improvement	cleaning products	polyurethane/alumina nanocomposites	100-1 000	<1
eyeglass/lens coating	household products / home improvement	cleaning products	nano polymer thin film coating	100-1 000	<1
anti-scratch/stick	household products / home improvement	cleaning products	various materials including alumina, silica, titanium, zirconium and silicon carbide	100-1 000	<1
filtration system	filtration, and purification	water filtration/purification	alumina	10-100	<1
sporting goods	sporting goods	equipment	composites (inc CNT)	10-100	<1
catalytic converters	motor vehicles	catalytic converters	platinum	10-100	<1
optical recording media	electronics and computer	recording media	alumina (thin film)	10-100	<1
catalytic converters	motor vehicles	catalytic converters	palladium	10-100	<1

Product group	Product category	Subcategory	Nanomaterial used in the consumer product		
			Chemical entity	Amount category (tonnes)	Relative presence on the market category (%)
xenon lighting	motor vehicles	lighting	alumina	10-100	<1
catalytic converters	motor vehicles	catalytic converters	rhodium	1-10	<1
ferrofluids	electronics and computer	electronic parts	iron oxide nanoparticles	1-10	<1
ferrofluids	electronics and computer	computer hardware	iron oxide nanoparticles	1-10	<1
fabric treatment	textiles and shoes	textile coating	polymer	1-10	<1
antimicrobial dressings	personal care and cosmetics	over the counter healthproducts	silver nanoparticles	0,1-1	<1
air purification systems	filtration, and purification	air filtration/purification	TiO2	<0.1	<1
toothpaste	personal care and cosmetics	oral hygiene	HAP (hydroxyapatite)	0 ¹	0
lithium ion batteries	electronics and computer	energy related	lithium nanoparticles	0	0
light emitting diodes	electronics and computer	lighting	quantum dots	0	0
light emitting diodes	electronics and computer	lighting	nanophosphor (quantum dots)	0	0
nanotubes - development	electronics and computer	display	carbon nanotubes (CNT)	0	0
nanotubes - development	electronics and computer	energy related (battery)	CNT cones	0	0
nanotubes - development	textiles and shoes	other textiles	CNT	0	0
anti-scratch/stick	motor vehicles	coatings	various materials including alumina, silica, titanium, zirconium and silicon carbide	0	0
transparent electrodes	electronics and computer	display	CNT	0	0
transparent electrodes	electronics and computer	energy related	CNT	0	0
nanocomposites	textiles and shoes	professional clothing	nanoclay (cotton)	0	0
algae preventers	filtration, and purification	water filtration/purification	lanthanum nanoparticles	? ²	?
diesel fuel additives	motor vehicles	fuel	CeO	?	?

¹ 0 because these products were not on the market in 2008 yet

² Amount of nanomaterials cannot be calculated because the price of the nanomaterial per kg is unknown

Table 4.8 The estimated relative presence of nanomaterials used in consumer products on the global market (%) in the near future, based on the total amount (tonnes) of nanomaterials used in consumer products.

Product group	Product category	Subcategory	Nanomaterial used in the consumer product		
			Chemical entity	Amount category (tonnes)	Relative presence on the market category (%)
coatings and adhesives	miscellaneous	coatings (and adhesives)	polymer	>10 000	30-40
food packaging	household products / home improvement	packaging	nanoclay	>10 000	20-30
catalytic converters	motor vehicles	catalytic converters	alumina	>10 000	1-10
insulation	miscellaneous	isolation material	silica aerogel	>10 000	1-10
UV absorbers	personal care and cosmetics	sun cosmetics	TiO ₂ , ZnO	1 000-10 000	1-10
automotive components	motor vehicles	interior	nanoclay, polymer, carbon	1 000-10 000	1-10
hard disk media	electronics and computer	computer hardware	chromium, cobalt and carbon	1 000-10 000	1-10
nanotubes - development	electronics and computer	display	carbon nanotubes (CNT)	1 000-10 000	1-10
photocatalytic coatings	household products / home improvement	cleaning products	TiO ₂ thin films	1 000-10 000	1-10
flat panel display	electronics and computer	display	polymer	1 000-10 000	1-10
wire and cable sheathing	electronics and computer	electronic parts	nanoclay	1 000-10 000	1-10
lithium ion batteries	electronics and computer	energy related	lithium nanoparticles	1 000-10 000	1-10
cladding of optical fibres	electronics and computer	electronic parts	silica based nanofilm	1 000-10 000	<1
eyeglass/lens coating	household products / home improvement	cleaning products	nano polymer thin film coating	100-1 000	<1
sporting goods	sporting goods	equipment	composites (inc CNT)	100-1 000	<1
anti-scratch/stick	household products / home improvement	cleaning products	polyurethane/alumina nanocomposites	100-1 000	<1
magnetic recording media	electronics and computer	recording media	iron oxide	100-1 000	<1
nanocomposites	textiles and shoes	professional clothing	nanoclay (cotton)	100-1 000	<1
anti-scratch/stick	household products / home improvement	cleaning products	various materials including alumina, silica, titanium, zirconium and silicon carbide	100-1 000	<1
transparent electrodes	electronics and computer	display	CNT	100-1 000	<1

Product group	Product category	Subcategory	Nanomaterial used in the consumer product		
			Chemical entity	Amount category (tonnes)	Relative presence on the market category (%)
transparent electrodes	electronics and computer	energy related	CNT	100-1 000	<1
filtration system	filtration, and purification	water filtration/purification	alumina	100-1 000	<1
nanotubes - development	textiles and shoes	other textiles	CNT	100-1 000	<1
anti-scratch/stick	motor vehicles	coatings	various materials including alumina, silica, titanium, zirconium and silicon carbide	100-1 000	<1
optical recording media	electronics and computer	recording media	alumina (thin film)	10-100	<1
catalytic converters	motor vehicles	catalytic converters	platinum	10-100	<1
catalytic converters	motor vehicles	catalytic converters	palladium	10-100	<1
nanotubes - development	electronics and computer	energy related (battery)	CNT cones	10-100	<1
xenon lighting	motor vehicles	lighting	alumina	10-100	<1
catalytic converters	motor vehicles	catalytic converters	rhodium	1-10	<1
ferrofluids	electronics and computer	electronic parts	iron oxide nanoparticles	1-10	<1
fabric treatment	textiles and shoes	textile coating	polymer	1-10	<1
ferrofluids	electronics and computer	computer hardware	iron oxide nanoparticles	1-10	<1
antimicrobial dressings	personal care and cosmetics	over the counter healthproducts	silver nanoparticles	1-10	<1
light emitting diodes	electronics and computer	lighting	quantum dots	0,1-1	<1
light emitting diodes	electronics and computer	lighting	nanophosphor (quantum dots)	0,1-1	<1
air purification systems	filtration, and purification	air filtration/purification	TiO ₂	0,01-0,1	<1
algae preventers	filtration, and purification	water filtration/purification	lanthanum nanoparticles	? ¹	?
diesel fuel additives	motor vehicles	fuel	CeO	?	?
toothpaste	personal care and cosmetics	oral hygiene	HAP (hydroxyapatite)	n.r. ²	n.r.

¹ ? = amount of nanomaterials cannot be calculated because the price of the nanomaterial per kg is unknown

² n.r. = not reported

4.7 Limitations with respect to market value analysis

As already mentioned in the beginning of this chapter, the specific information that is needed for the identification of consumer products with a high priority for future exposure studies can not directly be extracted from the market reports.

The market reports provide a lot of information on the commercial potential of various nanotechnologies for the near and mid-term future (2010-2015). For many nanotechnology applications the global market, consumption or sales is estimated, but this is not expressed relative to the total market, consumption or sales (including applications without nanotechnology). The reports identify specific segments of the nanotechnology market (e.g. consumer products, environmental remediation, electronics, etc.). Within these segments product categories (e.g. personal care and cosmetics, household products and home improvement, etc.) and subcategories (e.g. sun cosmetics, sun cosmetics, supplements, oral hygiene, etc.) are described, but generally no information on specific products (e.g. sunscreen, after sun, shampoo, etc.) or brands is provided.

The amount and type of nanomaterials in the consumer products can (indirectly) be estimated. In this way the consumer products containing the highest amount of nanomaterials have been identified. However, this is an indirect estimation since no information is available on the concentration of nanomaterials in the products.

For the product groups containing a large amount of nanomaterials (i.e. coatings and adhesives etc.), it is highly relevant to determine the possible exposure. However, a large amount of nanomaterials used in (the production of) these products may not necessary lead to a high exposure. The amount of nanomaterial used in the production process may not all end up in the consumer product itself (sometimes nanomaterials are used in the production process without incorporation into the consumer product). In addition, some nanomaterials are incorporated in consumer products in such a way that no exposure to nanomaterials is expected to occur during the use of the product by the consumer. However, one should bear in mind that during the rest of the lifecycle of the product, nanomaterials can emit to the environment via waste.

Furthermore, the amount of consumers can not be estimated based on the market reports, since no information on consumer behaviour and the exposed population is included in these reports.

In the next chapter the possible exposure to nanomaterials from different products is further analysed using expert consultation.

5 Expert consultation

5.1 Approach of expert consultation

As already mentioned in the introduction of chapter 4, the sequential step is the identification of exposure characteristics as well as the possible exposure to nanomaterials in consumer products. The identification of this possible exposure seemed very difficult because of the many uncertainties and lack of extensive information. In order to get a step further than just identifying the data gaps, the following approach was undertaken.

A panel of 7 RIVM nano- and consumer exposure experts was created and the experts were asked to separately carry out the following steps:

1. identification of the exposure characteristics that they considered important for the exposure assessment.
2. categorisation of the different consumer products described in the market reports into high (=1), medium (=2) and low (=3) possible exposure
3. explanation of categorisation per product
4. indication for each product on which of the identified exposure characteristics their categorisation was based.

5.2 Characteristics of the possible exposure

The exposure characteristics that are important for the exposure assessment, as identified by the expert panel, are described in Table 5.1.

Three main categories of characteristics are important for the exposure assessment of nanomaterials from consumer products. The first category of characteristics includes the properties of the nanomaterial in the consumer product. The chemical entity and the shape of the nanomaterial in the consumer product both are very important for the identification of the nanomaterial used in the product. Especially the way of incorporation of the nanomaterials into the consumer product (free nanoparticles or nanomaterials integrated into larger scale structures) and the concentration of the nanomaterial in the product are essential to predict possible exposure. Unfortunately, the concentration of the nanomaterials in the product is almost always unknown.

The second category of characteristics describes the application of the product. Where, how, how much, how long and by how many people is the product used?

Finally, the exposure route (via inhalation, ingestion or via skin) is an important characteristic.

Table 5.1 Main characteristics for human exposure to nanomaterials from consumer products

Important characteristics for the exposure assessment		Comments
Nanomaterial in consumer product	Chemical entity of nanomaterial	Actual composition of material
	Shape of nanomaterial (in product)	Thin films and coatings Composite Solid particle Hollow particle Other particle Aggregates Agglomerates
	Product form	Spray Powder Liquid Suspension Solid/ coating
	Free / fixed	Free particles Fixed inside matrix
	Concentration	Mostly unknown (based on mass?)
Application	Direct/ indirect exposure	Direct exposure to nanomaterials in the product or indirect via release of particles out of the product
	Indoor/ outdoor use	Inside or outside a small space
	Event duration	< 5 min 5 min-1 hr 1 hr - 1 day
	Frequency of events	> 1x/ day 1x/ day- 1x/ week 1x/ week - 1x/ month 1x/ month - 1 x /year
	Number of users in population	<10% 10-50% 50-90% > 90%
Exposure route		inhalation dermal oral combination

5.3 Categorising and ranking of products

All experts (n=7) categorised the different consumer products in high (=1), medium (=2) and low (=3) possible exposure. A total and mean score was calculated for each product. Not all experts were able to score all products, the number of scores varied between five and seven. Using the calculated mean score, a ranking of the products was made which is presented in Table 5.2.

Products with a mean score between 1 and 2 were categorised 'high' (dark grey colour), products with a mean score between 2 and 3 were categorised 'medium' (medium grey colour), and products with a mean score of 3 were categorised 'low' (light grey colour).

According to most experts, the possible exposure of nanomaterials from personal care products and cosmetics (including sun cosmetics, oral hygiene products, supplements and health products) scored high. Fuel for motor vehicles (after combustion) and do-it-yourself coatings, adhesives and cleaning products also got a high score from most experts. Catalytic converters, coatings and lighting for motor vehicles; display, recording media, energy related (battery) parts, electronic parts and lighting for electronics and computers; precoated coatings and adhesives; and sporting equipment got a low score from all experts who categorised these products. The other products were scored differently by different experts. A summary of the comments that are placed by the different experts as background for their categorisations can be found in Appendix 1.

Table 5.2 Ranking of consumer products on possible exposure by the expert panel (n=7)

Consumer category	Subcategory	Chemical entity	Mean Score
High			
Personal care and cosmetics	sun cosmetics	ZnO, TiO ₂	1,1
Personal care and cosmetics	oral hygiene	hydroxyapatite (HAP)	1,1
Personal care and cosmetics	health products	silver	1,3
Motor vehicles	fuel (after combustion)	cerium oxide	1,7
Miscellaneous	coatings and adhesives (do it yourself)	polymer	1,9
Household products and home improvement	cleaning products (do it yourself)	titanium dioxide, polyurethane, alumina, various materials	1,9
Medium			
Household products and home improvement	coating (do it yourself)	polymer	2,0
Textile and shoes	professional clothing	nanoclay, polymer, CNT	2,1
Textile and shoes	textile coating	polymer	2,3
Textile and shoes	other textiles	CNT	2,3
Motor vehicles	interior	nanoclay, polymer, CNT	2,5
Motor vehicles	fuel (when fuelling)	cerium oxide	2,5
Household products and home improvement	packaging	nanoclay	2,6
Filtration and purification	water filtration	alumina	2,6
Filtration and purification	water purification (for swimming pool)	lanthanum	2,6
Household products and home improvement	cleaning products (precoated)	titanium dioxide, polyurethane, alumina, various materials	2,6
Filtration and purification	air filtration	titanium dioxide	2,7
Electronics and computer	computer hardware	chromium, cobalt, carbon, iron oxide	2,7
Miscellaneous	isolation material	silica	2,8
Low			
Motor vehicles	catalytic converters	alumina, platinum, rhodium, palladium	3,0
Motor vehicles	coatings	various	3,0
Motor vehicles	lighting	alumina	3,0
Electronics and computer	display	CNT	3,0
Electronics and computer	recording media	iron oxide, alumina	3,0
Electronics and computer	energy related (battery)	CNT, lithium nanoparticles	3,0
Electronics and computer	electronic parts	silica, nanoclay, iron oxide	3,0
Electronics and computer	lighting	quantum dots	3,0
Miscellaneous	coatings and adhesives (precoated)	polymer	3,0
Household products and home improvement	coating (precoated)	polymer	3,0
Sporting goods	equipment	CNT	3,0

In Table 5.3 an overview is presented of the characteristics used by the experts for the categorisation of each product into high, medium, or low possible exposure. The number of experts that used the exposure characteristic for the categorisation of the individual consumer products is indicated in the table. Each number is marked with a different shade of grey, the more experts used the parameter, the darker the colour.

In total 6 out of 7 experts carried out the exercise, one expert did not provide this information.

Table 5.3 Characteristics which were most often used by the experts (n=6) to categorise the product

Consumer category	Subcategory	Characteristics used by the experts to categorise the product										
		Nanomaterial in product					Application					
		Chemical entity	Shape	Product form	Free / fixed	Concentration	Direct/ indirect exposure	Indoor/ outdoor use	Event duration	Frequency of events	Number of users	Exposure route
Personal care and cosmetics	sun cosmetics			4	6		5		1	1	1	5
Personal care and cosmetics	oral hygiene			3	5		5			1	1	5
Personal care and cosmetics	health products			2	6		5			1	1	4
Motor vehicles	fuel (after combustion)		1	4	5		3	4	2	2	2	5
Miscellaneous	coatings and adhesives (do it yourself)			5	5		5	2	2	2	2	4
Household products and home improvement	cleaning products (do it yourself)			4	5		5	2	2	2	1	4
Household products and home improvement	coating (do it yourself)			5	5		5	2	2	2	1	4
Textile and shoes	professional clothing			3	5		5		1	1	1	4
Textile and shoes	textile coating			3	5		5		1	1	1	5
Textile and shoes	other textiles			3	5		5		1	1	1	4
Motor vehicles	interior		1	3	6		4	4	2	2	2	4
Motor vehicles	fuel (when fuelling)		1	4	5	1	3	3	2	3	2	5
Household products and home improvement	packaging			3	5		5	1	1	1	1	4
Filtration and purification	water filtration			3	6		4			1	1	3
Filtration and purification	water purification (for swimming pool)			3	6		5	1	1	1	1	3
Household products and home improvement	cleaning products (precoated)			3	5		4	1	1			2

Consumer category	Subcategory	Characteristics used by the experts to categorise the product										
		Nanomaterial in product					Application					
		Chemical entity	Shape	Product form	Free / fixed	Concentration	Direct/ indirect exposure	Indoor/ outdoor use	Event duration	Frequency of events	Number of users	Exposure route
Filtration and purification	air filtration			3	6		5	1	2	1	2	3
Electronics and computer	computer hardware		1	4	6		4	4	2	2	1	3
Miscellaneous	isolation material			3	5		3	2	1	1	1	3
Motor vehicles	catalytic converters		1	4	6		3	3	1	2	1	
Motor vehicles	coatings		1	4	6		4	2	1	1		3
Motor vehicles	lighting		1	4	6		5	2	1	1		3
Electronics and computer	display		1	4	6		3	3	1	2	1	3
Electronics and computer	recording media		1	4	5		3	3	1	2	1	2
Electronics and computer	energy related (battery)		1	4	5		3	2	1	1	1	2
Electronics and computer	electronic parts		1	4	5		3	2	1	1	1	2
Electronics and computer	lighting		1	4	5		3	2	1	1	1	3
Miscellaneous	coatings and adhesives (precoated)			4	5		4	1	1	1	1	2
Household products and home improvement	coating (precoated)			3	5		5	1	2	2	1	4
Sporting goods	equipment			2	4		3		1	1	1	3

The most important characteristics for categorisation of the products were (see also Appendix 1):

- whether the nanomaterial was free or fixed inside the matrix of the consumer product,
- whether application of the product is expected to lead to direct exposure to nanomaterials or to indirect exposure via release of particles out of the product
- the route of exposure

Ad a. The possible exposure is expected to be high when the nanomaterial is/ nanoparticles are free, whereas the possible exposure is expected to be low (or not existing) when the nanomaterial is fixed inside the matrix and not expected to be able to migrate, leach, evaporate or otherwise get out of this matrix,¹.

¹ One should be aware that for these kinds of products the situation may be quite different at the end of the life cycle when disposal and waste management of these products is involved.

Ad b. The possible exposure is expected to be high when the product may lead to direct exposure when it is used by the consumer. When exposure to nanomaterials is only expected to take place via release of the nanomaterial out of the product (indirect exposure), the possible exposure is generally expected to be less than with direct exposure.

Ad c. Whether one route of exposure is expected to lead to a higher possible exposure than the other depends on the specific exposure situation. Some experts indicated that they used the expected route of exposure to get an idea of possible (external) exposure scenarios. Other experts used the expected route of exposure as an indication of the possible internal exposure. In the latter case, inhalation is generally expected to lead to higher internal exposure levels than dermal exposures. These and other differences in interpretation of the exposure characteristics are further discussed in the next paragraphs.

5.4 Limitations and uncertainties with respect to exposure characteristics

Different interpretations of exposure characteristics by the various experts make the interpretation of the overall ranking of the products difficult. In addition, for many products, the information on some of the characteristics is missing. These and other limitations and uncertainties with respect to the overall ranking are discussed for each of the exposure characteristics from Table 5.1.

5.4.1 Nanomaterial in consumer product

Chemical entity of nanomaterial

The list of the chemical entity of the nanomaterials mentioned in each sub category is not complete. Moreover, experts generally did not always focus on the indicated nanomaterials, but rather on the product category and sub category (regardless the chemical entity of the nanomaterial within the product).

Product form

For some products it is not clear how the nanoparticles are incorporated into the product. Sometimes different nanoparticles can be incorporated in various ways into different products within the same product category. For example, within the product category packaging, nanoclay is usually fixed into the matrix of PET bottles, while nano-silver is sometimes used as a surface coating in food containers. Another example, within the product category cleaning products (do it yourself) various nano-ingredients can be added to liquid suspensions which are used in different applications (added to cleaning water or sprayed on to a surface).

Free/fixed

One of the most important categories for the estimation of possible exposure was the presence of free versus fixed nanoparticles. Exposure from products in which the nanomaterial is fixed inside the matrix of the product is expected to be low, while exposure from products with free nanoparticles is expected to be high. Hansen et al. (2008) described a categorization framework in which products containing nanoparticles suspended in liquids and free airborne nanoparticles are expected to cause exposure. Although this report uses different terminology, these two categories are similar to what the experts in this report indicated as free nanoparticles. However, it is not always clear if and how the nanoparticles

are fixed in the matrix of the product and if they will stay fixed or migrate, evaporate, wash-out, and wear off, etc. during the use of the product. For example, nanoparticles within electronics and computers are usually fixed within the matrix of these products. However, some experts noted that it is not sure if they can migrate or evaporate from these matrices, in a similar way as for example flame retardants. Another example is the use of nano-silver in socks, which may wash-out in the washing machine or be released when wearing the socks.

Concentration

For most products the concentration of the nanoparticles within the consumer products is unknown and therefore this characteristic, although regarded as a very important characteristic in the exposure assessment, was generally not used by the experts in their ranking.

5.4.2 Application

Event duration and frequency of events

For some product categories (e.g. air filtration), the frequency of exposure events and/or the event duration is unknown.

Number of users in population

For many products the number of users within the population is unknown (mostly because it is unknown which percentage of the products contain nanoparticles, but sometimes also because the number of consumers using such products is unknown).

In addition, not all experts used this characteristic in their categorisation. Some experts considered only the individual exposure, while others also considered the part of the population they assumed to be exposed.

5.4.3 Exposure route

The expected route of exposure was interpreted by the experts in different ways. Some experts used the expected route of exposure to get an indication of possible exposure scenarios, while other experts used the expected route of exposure to get an idea of the expected internal exposure (the dose of nanomaterials that reaches the systemic circulation, organs and tissues of man). In the latter case, inhalation is generally expected to lead to higher internal exposure levels than dermal exposures. However, for most nanomaterials there is no data available on absorption after dermal, oral or inhalation. This makes the prediction of internal exposure even more challenging than the prediction of external exposure. Therefore, the final conclusions refer to external exposure and not to internal exposure, although when it comes to health risk assessment, the internal exposure is driving the risk.

5.5 Discussion of expert consultation

For several product categories all seven experts expected the possible exposure to be low (mean score of 3). The reason for this conformity among the experts is that the nanomaterials in these products are fixed inside the matrix of the product and are not expected to leach, migrate or evaporate out of this matrix during product use. In contrast, for the other products less conformity was observed, most likely because it is expected that some exposure to free nanoparticles may occur by using these products. However, the amount of free particles potentially causing exposure is unknown. According to most experts, the possible exposure is expected to be high for products that cause direct (usually intended) exposure to free nanoparticles when it is used by the consumer (e.g. sun cosmetics and oral hygiene products; liquid formulations).

Expert consultation was very useful but difficult to perform since the experts have various backgrounds. Therefore, various exposure characteristics are interpreted in different ways. Some of the exposure characteristics were not used for the categorisation by all experts (e.g. number of users in the population) or were used in different ways (e.g. exposure route). This makes it difficult to identify the most relevant characteristics in the categorisation of each specific product (category). In addition, careful interpretation of the ranking in Table 5.2 is necessary. A higher mean score does not necessarily mean that the possible exposure is expected to be higher for the individual consumer. A high score may also indicate a large number of users within the population, or a high frequency of exposure events, a long exposure duration, etc. However, this difference in interpretation is not expected to result in a significant different ranking of the products presented in Table 5.2.

The expert consultation made a semi-quantitative evaluation of the possible exposure from the various product categories possible, without extensive information on the exposure categories. In spite of the lack of information on some characteristics of some products, most experts were able to categorise most products into high, medium or low possible exposure.

The expert consultation resulted in the conclusion that personal care products and cosmetics (including sun cosmetics, oral hygiene products, supplements and health products) were expected by most experts (all but 1) to lead to the highest possible exposure. Fuels for motor vehicles (after combustion) and do it yourself coatings, adhesives and cleaning products were expected to lead to high possible exposure by fewer experts.

Recently, a Delphi Study on nanotechnology was published in Germany by BfR, in which more than 70 experts of different stakeholder groups were consulted to give their opinion on the field of nanotechnology in consumer products with respect to potential risks (BfR, 2009). The aim of the study was to make a grounded priority list of nano-applications for future risk assessments. This study gives a lot of insight and information on how different expert feel the nanotechnology market will develop in the future (specifically that of consumer products). Unfortunately, this report was published on such a short term that it could not be discussed in detail in this report anymore.

6 Conclusions and discussion

To identify consumer products with a high priority for future exposure studies, information on how many consumers use products containing nanomaterials is needed, including information on which products they use, how often and for how long. This type of information can not be extracted from either the product inventories or the market reports. With expert consultation, we tried to fill in these data gaps.

The analyses of the market reports, the expert consultation and the product inventories all have their limitations and uncertainties. However, combining the information may give an indication of the products with a high priority for future exposure studies. In order to identify these products, information from Tables 4.7 and 5.2 is combined together with the data from the product inventories. From Table 4.7, the first six product groups were taken and combined with the six products in the high exposure category of Table 5.2. Three additional categories important in the product inventories were added to this list. These categories are subcategories of the main category “Health and Fitness” of the WWI database as described in paragraph 2.2.1.

In Table 6.1 an overview is given on the overlap between the important product categories from the three analyses. Some product categories are important in two or all three analyses.

Table 6.1 Overview of the most important product categories identified from product inventories, market reports and expert consultation.

Product category	Subcategory	Product inventories	Market reports	Expert consultation
Personal care and cosmetics	sun cosmetics	+	+	+
Miscellaneous	coatings and adhesives (do it yourself)	+	+	+
Personal care and cosmetics	oral hygiene	+		+
Personal care and cosmetics	health products	+		+
Household products and home improvement	cleaning products (do it yourself)	+		+
Textiles and shoes	(professional) clothing	+		
Sporting goods	equipment	+		
Filtration and purification	filtration	+		
Motor vehicles	catalytic converters		+	
Motor vehicles	interior		+	
Miscellaneous	isolation material		+	
Electronics and computer	computer hardware		+	
Household products / home improvement	packaging		+	
Motor vehicles	fuel (after combustion)			+

Sun cosmetics, coatings and adhesives are important in all three analyses. Personal care products and cleaning products were judged important in the product inventories and in the expert consultation (for the subcategory sun cosmetics within the category personal care products UV blockers were also ranked high in the market analysis). Based on all three analyses, the product categories coatings and adhesives, personal care products (especially sun cosmetics) and cleaning products seem relevant for future exposure studies.

With respect to the near future (2010-2015), the same product categories were identified to be important within the market reports. In addition, no remarkable difference in the expert consultation is to be expected with regard to the importance of products categories in the near future. Most of the products that are still under development are expected to belong to the product category of “Electronics and computer”.

For future exposure studies, information on all the exposure characteristics as determined by the experts in Table 5.1 is needed. For the product category of sun cosmetics, concentrations of the nanoparticles and their size and shape in the product are very important since it is expected that there is a direct exposure to free particles. Furthermore, the market share of sun cosmetics containing nanomaterials compared to that of sun cosmetics without nanomaterials is important for the identification of the number of people within the population that are potentially exposed. Also data on consumer behaviour are important for the determination of the event duration and frequency of events. For a thorough exposure and risk assessment also more data on the product form (e.g. spray or liquid) are essential to identify the route(s) of exposure route.

In the case of coatings and adhesives, data on the form in which the particles are bound in the matrix or onto the surface are essential. Also information on possible migration or leaching of nanomaterials out of this matrix is needed. Furthermore, data on the product form are needed to determine possible exposure routes and data on consumer behaviour are very important for the determination of the event duration and frequency of events.

In the end, for determination of the health risks of consumer product containing nanomaterials, not only the (external) exposure needs to be estimated, also data on the internal exposure, kinetics and toxicity of the nanomaterials need to be determined in order to perform a robust risk assessment.

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Appendix I

Table A1: Comments of experts underlying the ranking of consumer products on possible exposure

Consumer category	Subcategory	Chemical entity	Comments of experts for ranking of products
High			
Personal care and cosmetics	sun cosmetics	ZnO, TiO ₂	Free nanoparticles, direct dermal contact to large parts of the body, also inhalatory exposure, high frequency of use, lot of users, if exposure to spray then high
Personal care and cosmetics	oral hygiene	hydroxyapatite	Direct oral exposure to nanoparticles, distribution and frequency of use unknown, risk is depending on passage through gut
Personal care and cosmetics	health products	silver	Direct, dermal exposure to free nanoparticles/ fixed particles that are released, intensive contact, damaged skin, few users but daily use, distribution/ frequency unknown
Motor vehicles	fuel (after combustion)	cerium oxide	Exhaust fumes, inhalatory exposure, outdoor, potential large source of exposure. Also nanoparticles after combustion? Consumer exposure? Emission to environment?
Miscellaneous	coatings and adhesives (do it yourself)	polymer	Direct dermal contact to free nanoparticles in liquid/gas, also inhalatory exposure, low distribution/ infrequent use, if exposure to spray then high
Household products and home improvement	cleaning products (do it yourself)	titanium dioxide, polyurethane, alumina, various materials	Free particles in liquid/ gas, dermal contact during use, also inhalatory exposure, distribution/ frequency of use unknown, if exposure to spray then high
Medium			
Household products and home improvement	coating (do it yourself)	polymer	Free particles in liquid/ gas, dermal contact during use, also inhalatory exposure, low distribution/ infrequent use, if exposure to spray then high
Textile and shoes	professional clothing	nanoclay, polymer, CNT	Nanoparticles fixed in matrix, possible release by sweating, intensive dermal contact with large parts of the skin, consumer exposure? more leaching, only dermal
Textile and shoes	textile coating	polymer	Nanoparticles fixed in matrix, possible release by sweating, saliva, intensive dermal contact with large parts of the skin, potential high distribution, limited contact
Textile and shoes	other textiles	CNT	Nanoparticles fixed in matrix, possible release by sweating, saliva, intensive dermal contact with large parts of the skin, high distribution, curtains, limited contact

Consumer category	Subcategory	Chemical entity	Comments of experts for ranking of products
Motor vehicles	interior	nanoclay, polymer, CNT	Direct dermal contact to fixed nanoparticles in matrix, not known if particles can be released due to sweating, indoor, potential high distribution
Household products and home improvement	packaging	nanoclay	Fixed nanoparticles, when migrating into food then oral exposure, distribution potentially high, possible accumulation in indoor environment
Filtration and purification	water filtration	alumina	Hardly contact of consumer with nanoparticles, unknown whether it is distributed in water, direct exposure, distribution/ frequency unknown
Filtration and purification	water purification (for swimming pool)	lanthanum	Hardly contact of consumer with nanoparticles, unknown whether it is distributed in water, direct exposure, distribution/ frequency unknown
Household products and home improvement	cleaning products (precoated)	titanium dioxide, polyurethane, alumina, various materials	Nanoparticles fixed in matrix
Filtration and purification	air filtration	titanium dioxide	Nanoparticles fixed in matrix, no migrating particles during use, distribution/ frequency unknown
Electronics and computer	computer hardware	chromium, cobalt, carbon, iron oxide	Fixed nanoparticles in closed application, , inhalatory exposure, particles hardly migrate, wide distribution of users, accumulation in indoor environment
Miscellaneous	isolation material	silica	Nanoparticles fixed in matrix, only dermal contact by installation of isolation material, hardly inhalatory exposure, distribution potentially high, accumulation in indoor environment
Low			
Motor vehicles	catalytic converters	alumina, platinum, rhodium, palladium	Fixed nanoparticles that hardly migrate, no contact for consumer, inhalatory exposure, outdoor, frequent use, when emission to environment, then high
Motor vehicles	coatings	various	Nanoparticles in matrix, dermal contact, paint, coatings are longlasting, no migrating particles during use
Motor vehicles	lighting	alumina	Fixed nanoparticles that hardly migrate, no contact for consumer
Electronics and computer	display	CNT	Low dermal contact with fixed nanoparticles in closed application, , inhalatory exposure, particles hardly migrate, wide distribution of users, accumulation in indoor environment
Electronics and computer	recording media	iron oxide, alumina	Low emission of particles out of product, hardly inhalatory exposure, high distribution, accumulation in indoor environment, frequent use
Electronics and computer	energy related (battery)	CNT, lithium nanoparticles	Fixed nanoparticles that hardly migrate, (only leaching batteries), no dermal or inhalatory exposure during use

Consumer category	Subcategory	Chemical entity	Comments of experts for ranking of products
Electronics and computer	electronic parts	silica, nanoclay, iron oxide	Fixed nanoparticles that hardly migrate, no contact for consumer, inhalatory exposure, outdoor, frequent use, when emission to environment, then high
Electronics and computer	lighting	quantum dots	Fixed nanoparticles that hardly migrate, no contact for consumer
Miscellaneous	coatings and adhesives (precoated)	polymer	Dermal contact of fixed particles in matrix, distribution potentially high, possible accumulation in indoor environment, only exposure by migration of particles
Household products and home improvement	coating (precoated)	polymer	Dermal contact of fixed particles in matrix, distribution potentially high, possible accumulation in indoor environment, only exposure by migration of particles
Sporting goods	equipment	CNT	No direct exposure to nanoparticles, no leaching out of matrix during use, to aspecific



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