Chances and Risks of Nanomaterials for Health and Environment

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Abstract. Nanomaterials have properties that are often very different from normal materials made of the same substance, which can be used to create novel products with exciting properties. However, the health and environmental impact of these nanomaterials is also changed and their potential risk needs to be studied. There is evidence that some nanomaterials can pass through tissue barriers (including the blood-brain barrier) and cell membranes. This is interesting for medical applications, but it raises concerns about the impact of non-medical nanomaterials. Current research aims at better coordinating research efforts and at better communication between researchers and involved stakeholders. Many research labs and production sites currently follow strategies that were established for dealing with very toxic chemicals and powders, until future research in this field helps identify the appropriate level of protection. All these efforts will ultimately ensure a safe, healthy and environmental friendly production, use and disposal of nanomaterials.

Keywords: nanomaterials, health, environment, risk assessment, occupational safety and health.

1 Introduction

Recent technological advances allow the targeted production of objects and material structures in the nanoscale (herein referenced as nanomaterials). The term nanoscale refers to scales in the size range between 1 and 100 nm (according to ISO/TS 27687:2008). Nanomaterials often have chemical, physical and bioactive characteristics, which are different from those of larger entities of material with the same chemical composition. This opens new possibilities for numerous applications and the "nano" market is currently one of the fastest growing markets[1].

Nanotechnology is expected to revolutionize medicine, as nanoparticles are small enough to enter individual cells and thus can act as carriers of therapeutic agents (nanomedicine) or as contrast agents for the imaging of tissues and diseases (nanodiagnostics) [2]. The information technology and computer industries are also heavily

[1] Lux Research estimates the market for pure nanomaterials to grow from $413 million in 2005 to approximately $3.6 billion by 2010. In comparison, the Lux forecast for the entire "nanotechnology impact" by 2010 is roughly $1,500 billion. [1].

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dependent on nanotechnology for many of their processes and products. Nanotechnology is starting to be used in many consumer products to improve the surface properties; the internal strength and durability of materials; the optical properties; or to reduce the requirement for precious raw materials.

Over 800 food and consumer products are already listed in the database of the Woodrow Wilson Institute [3], which is currently the largest inventory of consumer products with a declared link to nanotechnology. The list includes food additives and food packaging, textiles, cosmetics including sunscreens, magneto-opto-electronical components, construction materials, composite materials, household appliances, cleaning agents, and agricultural additives.

It is important to make a distinction between nanomaterials and nano-objects. The term nanomaterials defines materials that have at least one structural dimension on the nanoscale. This definition includes nanoscale patterning at the surface, or nanocomposites, where nanoparticles are permanently embedded into a bulk matrix structure. The interactions of such nanomaterials with living systems are limited by the fact that these nanomaterials cannot be taken up into tissues or individual cells. Nano-objects however, (particles with at least one dimensions in the nanoscale) are small enough to be taken up into individual cells, which provokes questions about the consequences of this uptake and the safety of these materials.

One can distinguish between products that were produced using nanotechnology and products that contain nanomaterials. In the first group of products, it is mostly the industrial processes where the potential exposure or release of nanomaterials is of interest, while in the second group, the fate of the nanomaterials remains of interest throughout the life-cycle of the products.

Another distinction that can (and should) be made is between manufactured and biological or natural nanomaterials. Many nanoscale entities occur naturally, such as protein assemblies and food emulsions. They can be re-engineering to have altered functionality, and therefore are somewhat in a grey area in terms of classification, as they have new functionality at the nanoscale but they are composed of natural (non-synthetic) materials.

The potential risks of nanomaterials for health and the environment must be assessed to allow for a sustainable development of the nanotechnology enabled industries and markets.

Despite recent advances in medical and toxicological research, it is still unclear exactly how nanomaterials interact with biological targets and which parameters of the nanomaterials drive these responses. Solid nanoparticles (nano-particulate material confined in three dimensions at the nanoscale) and nanorods (confined in two dimensions) in particular raise potential safety, health and environmental concerns. There is evidence that some of these materials pass through tissue barriers (including the blood-brain barrier) and cell membranes [4][5], and there have been reports of lipid oxidation, granulomatous tissue formation and other adverse responses to interaction with nanoparticles [6].

Little is known about the exposure of workers and consumers to nanomaterials, and the effectiveness of existing health and safety measures for industrial processes and consumer products is disputed [7]. This is a challenge for impact assessment studies. Even less is known about the environmental fate and impact of nanomaterials.

Thus, there are clear knowledge-gaps that need to be addressed. Importantly, current environmental and health protection strategies may not be adequate to prevent the safe environmental dispersion of nanomaterials or to protect human health.

2 Current Research Challenges

The main impediments that exist at present and hamper progress in the area of nanorisk assessment and the development of a framework for assessing nanomaterial safety are as follows:

- lack of awareness, communication and cross-talk between projects;
- the emphasis on toxicity as opposed to safety, which means that findings where no toxic response is observed tend not to be published;
- the lack of agreed standards, metrics and protocols for characterising nanomaterials and impurities at all stages before, during and after their interaction with living systems;
- lack of comparable cell lines, testing organisms and media, handling protocols and experimental protocols so that data from different groups are comparable and contribute to the overall body of knowledge in the field;
- lack of agreed exposure determination guidelines and standards;
- the almost complete absence of information about the behaviour of nanomaterials in environmental compartments and systems;
- a large uncertainty about how existing risk- and life-cycle assessment methodologies need to be adapted for nanomaterials;
- the large amount of data that presumable exists within industry that is not published and is therefore not available to the research community.

An important factor that contributes to the confusion and debate about the safety of nanotechnology is the lack of agreement on standards for experimental and measurement work. This makes comparison of results obtained by different groups almost impossible, and hampers progress. Many of the methods used to assess exposure are still too complex to be used in industrial settings and there is no agreed on strategy for the assessments of different exposure routes. Even more damaging, poorly characterised and purified nanomaterials, due to their extremely large surface area, can contain impurities in the form of soluble materials adsorbed to the surface, which may affect the outcome of the experiments. In contrast, surface-induced adsorption of cellular biomolecules, which affects the molecule's functionality, bioavailability and aggregation properties will be considered a nanoscale effect. Insufficient control for impurities therefore brings the risk that health effects may be falsely attributed to the manufactured nanomaterial. It is important to establish a common methodology and approach to determine the impact of nanomaterials on cells and organisms, and to assess human exposure.

Assessing the risks of nanomaterials requires an understanding of their mobility, bioavailability, persistence and toxicity and a lot of research is currently devoted to these topics. However, there is still insufficient knowledge available to make a realistic risk assessment of nanomaterials in the environment. Furthermore, very little is known about the expected quantities and concentrations of nanomaterials released

into environmental systems from an analytical point of view (e.g. actual measurements of anthropogenic nanomaterials in the environment) nor with respect to theoretical or modelling studies. The field of nano-ecotoxicology is still in its infancy. Both the modes and the degree of exposure are likely to grow in the next decades as the use of nanomaterials increases. Consequently, it will be important to create knowledge that can be used to evaluate the environmental impact of nanomaterials before they are produced in a large scale. It is important to develop standardized protocols to determine the fate and behaviour of nanomaterials in environmental compartments and to assess the hazard for a range of organisms and ecosystems.

Many industries assess the risks associated with their products, e.g. the medical device, food, pharmaceutical, cosmetics and chemical industries. It is reasonable to assume that those industries that are developing nanotechnology-enabled products are conducting safety evaluations, despite the fact that current regulations do not oblige them to do so for materials of equivalent chemical composition to ones that are already approved in bulk-scale. However, these data often do not get published in the scientific literature, and thus are not available to the wider scientific community[2]. However, it would be very helpful if information about nanomaterials that industry has found to be “safe” or "unsafe" were made more widely available to the scientific community. Strategies have to be developed to determine how this data could be made available in order to assess the methodologies that have been used to reach these conclusions, and to validate current testing practices.

Several national and European programs and projects aimed at investigating the risks associated with nanomaterials are already running. However, many projects were running in isolation, and experiences and findings that could benefit the research community at large were not effectively shared. Insufficient cross talk between these initiatives made it difficult for European researchers and stakeholders (industries, public interest groups, and policy makers) to access the knowledge created by these projects. In response to this challenge, the European Commission signed a contract with a consortium of 24 leading European research institutions for the creation of NanoImpactNet – The European Network on the Health and Environmental Impact of Nanomaterials (www.nanoimpactnet.eu), which was launched in April 2008.

The objective of NanoImpactNet is to create a widely supported scientific basis to ensure the safe and responsible development of engineered nanoparticles and nanotechnology-based materials and products, and to support the definition of regulatory measures and implementation of legislation in Europe. This framework includes a strong two-way communication, which ensures efficient dissemination of information to the various stakeholder groups (notably the European Commission, industry and SMEs, NGOs, and the general public) while at the same time obtaining input from these groups about their needs and questions. An important feature of this network is that it is open with regard to participation (everybody with a stake in the research can participate) and communication (conclusions and results are openly discussed and publicly available).

[2] Whilst regulators may not require this information under current regulations, there is an exception in the case of nanomaterials that are embedded in food packaging materials, where it is necessary to show that the material is inert and that additives do not migrate out of the material in unacceptable quantities (Framework Regulation (EC) 1935/2004 (L338/4)).

3 Nanomaterials in Research and Companies

Most of the above issues aim at mastering the risks of future applications of nanomaterials. However, nanomaterials are already now widely used in many research laboratories and also in selected companies. Consequently, the potential risks presented by the emergence of nanomaterials at the workplace need to be addressed already now with occupational safety and health strategies that seem appropriate to address the risks of the respective nanomaterials. Currently proposed strategies [8], [9], [10] were created in analogy to strategies for dealing with chemical and powder risks. Some users and producers already apply these proposed strategies – even though (too) many still seem to rely solely on personal protective equipment [11]. In contrast to the above-mentioned analogy-based approaches, more recent efforts aim at developing strategies that target nano-specific aspects [12]. Recently, the Swiss Government published a precautionary matrix that allows an initial assessment of the risks of nanomaterial applications without requiring detailed knowledge on the toxicology of the nanomaterials involved [13]. Such preliminary information is essential for simplified, so-called control-banding approaches that group risks in broad classes and then define different levels (or bands) of protection efforts [14].

Occupational safety and health is expected to also profit in future through the application of nanotechnologically-produced materials. Light, strong and chemically persistent material will enable the production of more comfortable occupational safety equipment such as safety boots or protective clothing. Even more importantly, novel surface treatment technologies might allow to strongly reduce or even completely eliminate the use of some aggressive chemical and physical procedures that are often needed when cleaning equipment that gets in contact with liquids in the chemical, food and pharmaceutical industry, thus eliminating very important risks from the factories and the workplaces. These potential future applications show that workers (and also researchers developing such products) are likely to not only be those that bear the risks, but they also will profit from the benefits of nanotechnological progress.

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