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Mini-Symposium: Nanoparticles and Children's Lungs

Airborne Engineered Nanoparticles: Potential Risks and Monitoring Challenges for Assessing their Impacts on Children

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SUMMARY

Engineered nanoparticles (ENPs) are the building blocks of novel materials and consumer products that hold great promise for our societies. When ENPs are released to the environment, however, they can induce irreversible processes that can affect human health. To ensure safety for all nanoparticle-based products throughout their life cycle we urgently need to develop techniques for determining their toxic effects and the exposure levels of humans to ENPs. In an attempt to estimate whether nanotechnology can threaten more sensitive parts of the population such as children, we provide a brief overview of the potential pathways of introducing ENPs into the environment and the state-of-the-art techniques for assessing human exposure, as well as our current knowledge on their toxic effects.

INTRODUCTION

Advances in nanotechnology over past decades have offered novel materials that would not be possible with bulk systems. The enhanced performance of these materials is the result of the unique properties of their building blocks, the engineered nanoparticles (ENPs). Under the term nanoparticle we define any particle that has at least one of its dimensions smaller than 100 nm. The properties of such structures can differ markedly from those of their larger counterparts and of bulk materials due to the high surface-to-volume ratio and electron confinement.

Nanomaterials and ENPs are finding applications in structural engineering, electronics, optics, consumer products, energy production and storage, soil and water remediation, as well as in medicine for therapeutic or diagnostic purposes.[1] At present, a large portion of ENPs is made of carbon, metals, and metal oxides. Carbon-based nanoparticles, including nanofibres and nanotubes, are currently being employed in a wide range of materials to enhance their mechanical properties. Metal and metal oxide nanoparticles are used in the fabrication of catalytic converters, in paints, as well as in diagnostic imaging and in drug delivery.

Research in nanotechnology incorporates the development of processes for producing well-defined ENPs and the techniques for assembling them to nanomaterials. Nanoparticles can be synthesized in the gas or the liquid phase. Gas phase (aerosol) techniques provide flexible ways of producing nanoparticles of high purity.[2,3] Liquid phase (hydrosol) methods on the other hand are less flexible but can offer higher mass production.[4,5] This is the main reason that, despite the increased amounts of waste formation, they have been more widely used for producing ENPs. Concerns on sustainability in connection with producing ENPs are driving researchers to upscale gas phase processes that produce less waste.

Once produced, ENPs can be further functionalized by modification of their surface composition. Commonly, organic molecules (e.g., polymers or surfactants) are added onto the surface of nanoparticles to increase their functionality, thereby tremendously expanding the variety of potential applications. This versatility of ENPs has driven global investment in nanotechnology research and development by public and private sectors to a few tens of millions of EUR annually. Penetration to the market currently counts more than 1300 consumer products that employ ENPs in one way or another.[6]

With the rapid growth of nanotechnology, the assessment of the potential environmental and health risks is lagging behind.[7] Once released into the environment ENPs can undergo diverse physicochemical transformations that change their properties, their fate, and their environmental impacts. There is increasing concern that human exposure to some types of ENPs, inadvertently or intentionally, can lead to significant adverse health effects.[8] The more sensitive parts of the population, children in particular, necessitate extra efforts towards assessing hazards and exposure.

Public awareness and governmental involvement in overseeing the developments of nanotechnology industry is not keeping up with the rapid pace of development and commercialization of nanoparticle-based products.[4] The details of the processes for producing ENPs in industry, the quantities in which they are being

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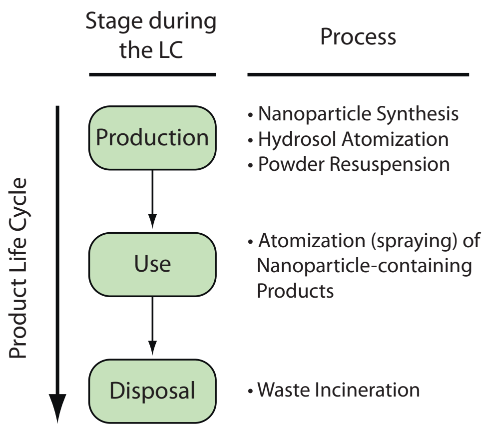

Figure 1. Processes that can lead to airborne ENPs at the different stages of the life cycle (LC) of nanoparticle-based products.

produced, and how they are being handled and used remains largely uncontrolled. This is also reflected by the fact that leading insurance companies have characterised nanotechnology as one of the highest emerging risks, indicating that a continued lack of data could increase the insurance costs of nanotech companies.[9]

To assess the risks involved in producing, using, and disposing nanotech products we need to fully understand their hazards (i.e., their toxic effects) and the degree of exposure for certain parts of the human population to ENPs throughout the complete life cycle, i.e., from production to disposal (cf. Figure 1). Because inhalation is the most important route of introducing ENPs into the human body,[10] particular focus is given to the processes by which ENPs can be transferred into the air we breathe and their toxicity when they enter the human respiratory system. Focusing only on the airborne ENPs, we provide a brief overview of the various paths via which they can be introduced into the environment, the state-of-the-art techniques for exposure monitoring, as well as our current understanding of their toxic effects on humans. The confrontation with nanotoxicity as a new category of toxicity, little of which is known, is of special relevance to children, because they are more vulnerable than adults in many respects.

SCENARIOS OF HUMAN EXPOSURE TO ENPS

Nanoparticles in the environment can enter the human body through the respiratory tract, the gastrointestinal tract, or the skin. Inhalation of ENPs suspended in the air is regarded as the most important route for their entrance into the human body for various reasons.[10] Nanoparticles in the air can remain suspended over long periods of time, thereby spreading over long distances from the point of their release. As a result, humans can be exposed to airborne ENPs in an uncontrollable manner compared to the other routes. In addition, because the lung is an organ with a large surface area, nanoparticles in the inhaled air are very efficiently transferred and translocated into the human body. This section provides a brief overview of the various mechanisms of introducing ENPs into the air we breathe at the different stages of the life cycle of nanoparticle-based products, as well as the techniques for measuring nanoparticles in the breathing air.

Exposure to ENPs at the Production Stage

ENPs can be released to the atmospheric environment during their gas-phase synthesis on the workfloor of industries producing nanoparticle-based materials. Commonly gas phase ENP synthesis routes are based on condensation of supersaturated vapours from flames or plasmas.[5] These are highly versatile processes for producing nanoparticles of various materials, sizes, and morphologies. Apart from vapour condensation, another possibility for synthesizing ENPs is by aerosolisation of precursor-containing solutions into very small droplets. Upon evaporation of the droplets, residual solid nanoparticles remain in the gas phase. Presently, most of these processes lead to particles in the micrometer size range, but research is rapidly expanding in the direction of the nanometer size range. Alternatively, nanoparticle-containing colloids can also be aerosolized. In this case the nanoparticles, or clusters of nanoparticles present in the colloid, remain in the gas phase upon evaporation of the solvent.

Nanoparticles synthesized in gas suspension are either processed further, e.g. to produce functionalized coated nanoparticles, or used directly for the fabrication of nanomaterials and nanoparticle-based products. In these processes ENPs often go through the state of dry powders. The handling of nanopowders is another stage in the production line where ENPs or small inhalable flakes of nanoparticles can be released to the environment.[11] Very little is known about the significance of this effect, and studies are underway.

Synthesis of ENPs in the gas phase and handling of nanopowders is always performed in sealed reactors to prevent release of the particles to the breathing air. The only way that ENPs can escape from the reactor is through accidental spills, in which case the production process has to be stopped and the area evacuated. Although safety measures are available and employed, accidental spills can release high concentrations of ENPs depending on the size of the production facility. When liquid phase methods[6,7] are employed for synthesizing nanoparticles, their introduction to the environmental air can happen through inadvertent atomization of the particle-laden liquid suspensions (hydrosols). However, the chances of getting ENPs into the atmospheric environment through liquid phase methods are negligible compared to those of gas phase techniques.

Exposure to ENPs When Using Nanoparticle-based Products

The next possible stage where humans can be exposed to ENPs is during the use of nanoparticle-based products. In consumer products, however, nanoparticles are usually tightly bound to a surface or integrated into a matrix, making direct contact of humans to nanoparticles practically impossible. Nevertheless, there is a small number of nanoparticle-containing products, the use of which can lead to direct exposure.

Food products can contain nanoparticles in the upper nano range to control the texture and the rheology of the food.[12] These nanoparticles are in most cases water-soluble and biodegradable and thus do not affect human health as a result of their size upon introduction to the human body via the gastrointestinal system. Fabrics and textiles can also contain ENPs, mainly silver nanoparticles, as an antimicrobial agent. In this case, humans can be exposed to ENPs through direct contact with the skin, or indirectly when the nanoparticles contained in the fabrics are released through washing to the aquatic environment.[13] Neither of these categories of consumer products can lead to inhalable nanoparticles, and therefore pose minimal risks according to present knowledge.

Aerosolisation (spraying) of ENPs is also used in consumer products. Although spraying of liquids within spray cans produces relatively large droplets (larger than 10 μm), there is a possibility that charge-induced fragmentation[14] (an effect that has hardly been studied) leads to nanoparticle formation. Some commercial sprays for treatment of surfaces (e.g., shoes and garments) can contain nanoparticles to induce, e.g., antiseptic and/or non-wetting behaviour.[15] If nanoparticles are suspended in the sprayed liquid, evaporation of the droplets forms clusters of nanoparticles in the inhalable size range.