DECHEMA e.V.
Society for Chemical Engineering and Biotechnology

VCI
German Chemical Industry Association

Environmental Aspects of Nanoparticles

– with a priority list for the European 7th R&D Framework Programme and national research programmes –

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Opportunities and risks of manufactured nanomaterials – environmental aspects

The application of nanotechnologies and the use of manufactured nanomaterials have the potential to significantly reduce the environmental impact of technical processes and products. New and innovative materials which, at the same time, have a lower weight and are more stable can help to reduce the consumption of energy and resources. Dirt repellent surfaces reduce cleaning efforts and hence the consumption of water and cleaners. Nanomaterial based sensors and membranes will have a positive impact on the detection of contaminants and on the cleaning of water and the environment from pollutants. Enhanced fuel cells, solar panels and high-capacity batteries will save primary energy consumption, allow a more effective use of regenerative energy sources and will help constructing cars with lower carbon dioxide emissions.

Besides these positive effects, also potential negative effects of nanomaterials must be considered. Especially, potential negative effects of free nanoparticles on the environment must be explored early on. Typical questions are:

- Can special nanoparticles harm certain compartments of the environment?
- Is there a release of nanoparticles from sun creams, coatings and paints to the environment?
- What is the fate of released nanoparticles? What is their impact on water and soil? Are there any unforeseen effects?

In Germany, DECHEMA and VCI have established as early as 2003 the joint working group "Responsible Production and Use of Nanomaterials" which consists of high-level European academic and industrial experts and is regularly joined by representatives from German authorities. The group shares scientific findings and best practices on safety aspects of the production and use of nanomaterials.

In this document, the DECHEMA/VCI working group has addressed environmental aspects. The document describes in a first part ("A") some anticipated positive environmental effects using manufactured nanomaterials. The list in the second part ("B") addresses open research topics to evaluate the potential risks associated with the release and fate of nanoparticles from end products during manufacturing, handling, use and disposal. The list describing future priorities for R&D is divided in two categories, describing high priority, and medium and low priority projects, respectively.

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A. Positive environmental effects of manufactured nanomaterials

The application of nanotechnologies and the use of manufactured nanomaterials have the potential to significantly reduce the environmental impact of technical processes and products. In addition, the use of nanomaterials may lead to innovation in other sectors, such as the health, medical, automotive, aeronautics and energy sectors. Some examples of positive environmental effects using nanomaterials are given below. There are many other promising areas and applications for manufactured nanoparticles.[1, 2, 3]

- Catalytic steps are widely used in the chemical industry. Nanoscale catalysts significantly reduce the use of raw materials and minimize side streams and energy consumption. One striking example are the automotive catalysts, reducing hydrocarbon, nitrogen oxide and carbon monoxide emissions by 90%. In mobile as in stationary applications, nanomaterial based catalysts and filters will lead to cleaner combustion processes and hence a reduction of emissions. Also, by using nanomaterials, the efficiency of regenerative energy sources like solar cells can be improved. Manufactured nanomaterials significantly improve efficient and low cost methods for energy transformation and storage (i.e. fuel cells and lithium ion batteries), enabling low emission and low fuel consumption cars.

- Water purification can be made more effective by using nanosized/nanostructured materials. Membranes and highly sensitive nanostructured sensors enhance the early recognition of pollutants before damage can occur. In addition, nanomaterials can substitute (eco-)toxicological hazardous substances (i.e. flame retardants and toxic corrosion inhibitors).

- Useful for the health sector is the coating of implantation materials with biocompatible surfaces or easy-to-clean surfaces due to nanocoatings with biocidic or anti-adhesion properties. New drug delivery systems based on manufactured nanomaterials to cure, e.g., neurodegenerative diseases are of strong interest for the pharmaceutical sector.

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[1] publifocus "Nanotechnologien und ihre Bedeutung für Gesundheit und Umwelt"
Nanotechnologien in der Schweiz: Herausforderungen erkannt
Bericht eines Dialogverfahrens
Zentrum für Technikfolgenabschätzung
TA-P 8/2006 d, Bern, 2006, ISBN-Nr. 3-908174-25-2
[2] NanoRoad SME: http://www.nanoroad.net
[3] Nachhaltigkeitseffekte durch Herstellung und Anwendung nanotechnologischer Produkte, Schriftenreihe des IÖW 177/04, Berlin

B. Release of nanoparticles from end products during manufacturing, handling, use and disposal – research priorities for analysis and assessment of effects

High priority topics

Development of methodologies for effect assessment
1. Development of globally harmonised methods for measuring environmental impact and ecotoxicity (standardisation is recommended) ➢ Investigation to find out whether existing methods can be applied for measuring environmental impacts of nanoparticles. If necessary, the test procedures will have to be adapted with respect to standard sample preparation (stirring, ultrasound mixing, filtration, etc.). The test methods should include all kinds of solvents and should consider possible side effects, such as the interaction of nanoparticles with the analytical samples. ➢ Development of a standard procedure for the determination of the particle size during individual tests
2. Identification and preparation of reference nanoparticles ➢ Identification and definition of long-term producers and suppliers of the identified reference materials ➢ Identification of the main parameters for the characterisation of the nano-state of the reference materials
Substance properties
3. Determination of agglomeration/segregation of specific nanoparticles (stability of the nanoparticle state); generalisation of the results to develop a standard model for agglomeration/segregation ➢ Determination of the conditions and the rate of agglomeration/segregation of specific nanoparticles ➢ Investigation of the thermodynamic principles regulating "phase transitions" and of relevant physical properties of the particles ➢ Investigation to discover whether the behaviour of nanoparticles depends on the structural properties and whether the effect can be generalized ➢ Comparison of the kinetics of standardised material ➢ Development of a standard procedure for the determination of particle size during individual tests
4. Life-cycle aspects (disposal of dusts, recycling) ➢ Investigation of the emission of nanoparticles from products during their life cycle ➢ Performance of life-cycle assessments for different nanoparticles or for one example of a relevant nanoparticle used in different applications ➢ Investigation of direct environmental effects (e.g. release of nanoparticles into the environment, stability of nanostructures) and indirect effects (e.g. disposal of dusts, recycling, energy demand and carbon dioxide emissions) ➢ Assessment of the natural background of specific materials (iron oxides, titania, silica)

High priority topics (continued)

Behaviour and fate in the environment
5. Determination of the mobility of persistent manufactured nanoparticles in surface waters, groundwaters and soils (depositions, mobilisation, adsorption, desorption, kinetics, distribution, morphology) and the master parameters governing their mobility ➢ Modelling of the diffusion and dispersion of nanoparticles in water, soil and air ➢ Development of models describing the interaction between the nanoparticles and other substances in the compartments ➢ Investigation to find out whether other substances, e.g. dissolved organic matter, may influence the stability of the nanostructure and/or possible ways of transportation
6. Development of methodologies which are able to identify and quantitatively determine nanoparticles in the environment (air, water, soil) at relevant (i.e. low) concentrations. ➢ Methods must be able to distinguish between naturally occurring nanoparticles and manufactured types of nanoparticles.
7. Determination of the background burden of nanoparticles in the environment to estimate the contribution of anthropogenic sources ➢ Background burden includes natural colloidal nanoparticles and unintentionally released nanoparticles (e.g. from combustion processes) and needs to comprise all environmental compartments (soil, water, air). ➢ An intensive exchange with other projects is recommended in which determination/quantification of nanoparticles at the workplace or in living cells is already a topic. ➢ Development of methods for on-site analysis might be interesting (instrumentation which is easy to handle and to transport and results can be achieved in a short time on-site).
Effects on organisms
8. Investigation of the uptake of persistent nanoparticles by living organisms/ microorganisms (in-vivo and in-vitro). Compilation of information on toxicokinetics, deposition and accumulation of persistent nanoparticles. ➢ The living organisms/microorganisms used should be the relevant species from standard toxicity testing. ➢ Investigations should consider different routes of uptake and kinetics.

Medium and low priority topics

Development of methodologies for effect assessment
1. Development of methods (in-vivo/in-vitro correlation) to transfer the results of ecotoxicological investigations with idealised nanoparticles to real formulations in order to minimize animal tests ➢ Deriviation of suitable uncertainty factors, QSAR modelling, consideration of matrix effects
2. Development of methods to extrapolate the results of ecotoxicological tests to chemically similar nanoparticles with different forms, surface modifications and size ➢ A combination with topic no. 3 of the high priority topics should be considered
Substance properties
3. Investigation of binding and mobilisation (particle-based transport mechanisms) of toxic manufactured nanoparticles (e.g. heavy metals and toxic hydrocarbons) ➢ Discrimination between contaminations that enter the environment together with the manufactured particles or that are mobilised in the environment by binding to the manufactured particles ➢ Follow-up of topic no. 5 of the high priority topics: interaction between particles and other substances in the compartments
Behaviour and fate in the environment
4. Investigation of the persistence (accumulation, degradation) of nanoparticles in the environment ➢ A combination with topic no. 5 of the high priority topics should be considered
5. Investigation of the fate of remediation products ➢ Investigations of the fate of the nanoparticles after use
Effects on organisms
6. Investigation of the biokinetic fate of persistent nanoparticles in the food chain ➢ Investigation to determine whether nanoparticles remain in the food chain in nanostructured form ➢ Investigation of effects on organisms; comparison of nanoparticles and the corresponding bulk material ➢ Detection of nanoparticles and nanomaterials in the food chain that do not exist in the natural environment (e.g. fullerenes or carbon nanotubes)