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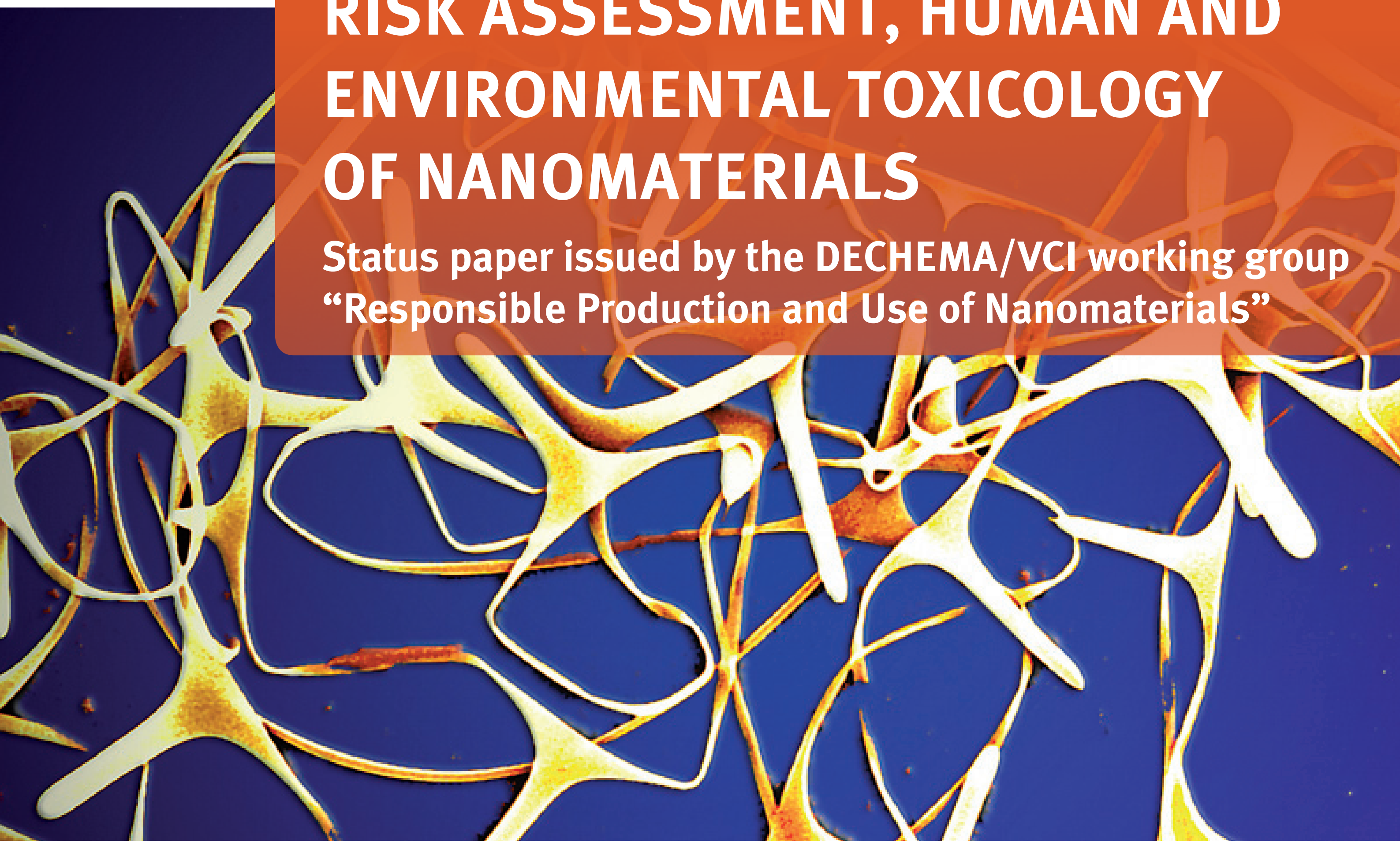
10 YEARS OF RESEARCH: RISK ASSESSMENT, HUMAN AND ENVIRONMENTAL TOXICOLOGY OF NANOMATERIALS

Status paper issued by the DECHEMA/VCI working group "Responsible Production and Use of Nanomaterials"



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EXECUTIVE SUMMARY

In the future, nanotechnology and the resulting nanomaterials may represent the major key for solving the most important challenges facing our society in a range of pivotal areas of fundamental needs, including energy, the environment, climate, efficient use of resources, mobility, safety, information/communication, health and food supplies. In order to be able to make sustainable use of the opportunities offered by this technology, it is vital to ensure the safety of nanomaterials in their applications along their respective value creation chains and lifecycles.

In the past decade, a large number of projects has already been started up and carried out in order to conduct research into the safety of nanomaterials, and these projects have delivered a series of important results for different nanomaterials. The following general conclusions can be drawn from the projects carried out to date under realistic conditions:

» A **risk assessment** – where necessary in individual cases - should be performed on the basis of suitably modified and adapted OECD methods which have been validated and are internationally recognised. This confirms the OECD observation that the internationally recognised OECD methods and testing guidelines are suitable in principle for the testing of nanomaterials.

» The size label '**nano**' does not also immediately mean ‚toxic', so it **does not represent an intrinsic hazard characteristic**.

For the benefit of all of society, the continuous transfer of research results from the laboratories into successful innovations should be continued, and this process should be supported with accompanying safety research. The following will be required for this safety research:

» financial means, combined with sufficient numbers of suitably qualified research scientists;

» coordinated research into areas of interactions between nanomaterials and humans and the environment, so that individual results can be combined into structure-activity relationships which can then be used as signposts for new, safe nanomaterial developments;

» compliance with research standards (e.g. through Standard Operating Procedures, SOPs) in order to ensure comparability and reproducibility of results;

» publication of negative research results as well, i.e. studies in which no toxicological effects of nanomaterials could be displayed, so that the overall picture is not distorted;

» topical assessment of lifecycles as soon as corresponding commercial applications start to emerge.

These scientific investigations and approaches should be supplemented with measures to inform and engage in dialogue with the general public, so that they can understand the opportunities and safety aspects of nanomaterials, and hence the level of acceptance for this technology can be increased.

I. Introduction

Our global society currently faces a large number of challenges, and how we meet these challenges in the future will depend on our ability to harness a wide range of new technological tools and building blocks. Safe and sustainable usage of nanotechnology and nanomaterials in particular can offer many different and far-reaching approaches which will benefit mankind and the environment. Nanotechnology can therefore be one of the keys to solving the imminent problems faced by our society in a number of different pivotal areas of fundamental needs:

» For example in the area of energy and mobility, where new materials can be used to achieve more efficient energy conversion on the basis of renewable energy sources and through improved, more efficient energy storage and usage.

» For protection of climate, environment and resources, among other things through more efficient usage of resources with the aid of specific catalysts and processes, and therefore also - e.g. thanks to the avoidance of unwanted by-products - the cleanup and rehabilitation of air, water and soil with the aid of nanomaterials.

» In terms of protecting and restoring health, for example through improved UV protection substances in sunscreens and textiles and through new treatment methods e.g. in the field of cancer treatments, but also in the area of packaging, which can help to increase the shelf life of food products in developing countries which would otherwise quickly go off on their way to the consumer.

» Increased everyday safety can be achieved e.g. through earthquake-proof buildings, and more efficient crash elements can help to improve impact protection for vehicle occupants and pedestrians in road traffic accidents.

» In the field of communication/information, microchips based on nano-scale switching elements are already an integral part of modern systems; these products have already been using “nanochips” for some time now. Storage media and new information processing concepts are surely set to continue this trend.

Thanks to the wide-ranging nature of these different fields, nanotechnology and nanomaterials will form part of the requirements for numerous far-reaching innovations along the value creation chains in many areas of industry in the German, European and global economy.

Consequently, major effort has been and is being put into research and development in order to turn the potential opportunities of nanotechnology into successful innovations. As a result, huge investments have been made into nanotechnology research and development in Germany and Europe in recent years. Today, Germany has already established itself as one of the leading research countries in the world in this sector. Based on the excellent research results which have already been obtained, the aim in Germany is now to successfully implement these developments in products and applications in as many as possible of the areas of need outlined above. A key aspect of this transfer of research results into sustainable innovations is the requirement that we must ensure the safety of these products and applications based on nanotechnology and/or nanomaterials along their entire lifecycles. For this reason, during the past decade the product/application research and development which has been carried out has also been accompanied by a number of activities conducted by industry and universities to investigate the safety of nanomaterials. This work has been publically funded to a large extent, and the projects have already delivered many useful results.

Overall, Germany has assumed one of the leading positions both across Europe and globally in terms of research into the safety of nanomaterials. Among other things, this is thanks to a constructive dialogue about the opportunities, challenges and safety aspects of nanotechnology which was already set in motion at a very early stage by a number of different groups. This dialogue has seen active involvement from representatives acting on behalf of end users, e.g. environmental and consumer protection lobbyists, politicians, public authorities, but also research scientists at universities and other institutions and - in particular - also representatives from the chemical industry, which is well aware of its responsibilities. As the producer of nanomaterials, the chemical industry examines the safety aspects of nanomaterials within the framework of its “Product Stewardship” programmes and recognises the accompanying safety research as an integral part of its innovation strategy.

For more than three decades now, research has been conducted into materials, the smallest units of which are in the region of just a few nanometres. For example, research into the safety of micro and nano-scale materials was already carried out as far back as the 1980s and 1990s, albeit under the headings of 'colloids' and 'ultra-fine dust' which were used at the time and which are at least in part equivalent to the modern 'nano' terminology. One example here is the papers prepared on magnetic nanoparticles by Peter Gehr together with Jo Brain at the Harvard Medical School, which were already published at the start of the 1980s in Nature. After the introduction and subsequently rapid and far-reaching spread of the name 'nanotechnology' in the last decade, the issue of safety aspects of nanomaterials has increasingly also been explored directly in research projects in order to bridge existing knowledge gaps.

The DECHEMA/VCI working group "Responsible Production and Use of Nanomaterials" has drawn up a list of topics and priorities which need to be addressed here, in which the activities and projects which have already been carried out, are currently on-going or are still at the planning stage are entered and classified.

However, in terms of research into the safety of nanomaterials, academia and industry often address different aspects:

On the one hand, research groups - especially university groups - tend to steer their projects towards research into more fundamental aspects, such as the fundamental principles of the action mechanisms involved in the interaction between nanomaterials and biological systems, and they develop fundamental methods for detection and characterisation.

On the other hand, industrial "Product Stewardship" programmes assess the safety of products along their lifecycles, i.e. in manufacturing, further processing and in the planned applications. Consequently, these efforts are focused primarily on the products brought to market by the relevant companies.

Above and beyond the two aspects mentioned above, joint consortia made up of representatives of industry and academia can systematically develop fundamental mechanisms on commercially relevant systems or systems which are close to real-life applications. In combination, these should yield coherent structure-activity relationships, which can play a supporting role in influencing future product developments in industry.

In order to ensure that "nano" based products are safe, basic risk assessments are required for them, both in terms of their intended applications and in relation to their full lifecycle along value creation chains. According to the opinions of the relevant experts of the Organisation for Economic Cooperation and Development (OECD) and the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) of the European Commission, these risk assessments can, in principle, be carried out with suitably adapted, validated and internationally recognised (e.g. OECD) methods. From these, it will then be possible to derive appropriate measures (e.g. safe limits for the workplace) which will enable safe production, further processing, usage and recycling/reuse in the relevant value creation chain.

The following varied factors and considerations must all form part of such a risk assessment: on the one hand, it needs to be investigated whether and, if applicable, to what level any release, i.e. emission of nanomaterials and/or nano-objects, is at all possible in an intended application. Furthermore, clarification needs to be sought whether the nanomaterials and/or nano-objects which may potentially be released can interact with surrounding biological systems, i.e. whether any exposure actually occurs in the relevant application.

On the other hand, the interactions of the nanomaterial under assessment and its effects on biological systems, i.e. humans and the environment, need to be examined and classified under defined conditions, e.g. via a range of different exposure routes (oral, dermal, by inhalation etc.) and at different doses, i.e. exposure levels. As a result, not only are the possible exposure scenarios in the application of the nanomaterial and/or nano-object and its biological effects examined in isolation, but in order to properly conduct a risk assessment of a material in an application, both factors also need to be combined with each other in order to allow a general risk assessment to be concluded. This means that, for example, the absence of a relevant exposure in an application and/or the absence of a negative biological interaction during an expected corresponding exposure would indicate the absence of any risk in a given application.

For relevant studies carried out for safety assessments, this therefore means that the biological effect (factor 1) needs to be systematically investigated under defined test conditions (defined test set-ups and comparison systems, characterised materials, defined exposure paths and exposure doses). In addition, realistic scenarios need to be drawn up for the relevant application and corresponding exposure doses (factor 2) and exposure paths.

By combining the mutually coordinated investigations into both factors, it will then be possible to perform a reliable risk assessment, from which it will also be possible to derive appropriate measures to minimise the risks associated with this application throughout the lifecycle.

A range of such studies designed to deliver safety-related data for nanomaterials has already been conducted or is currently in progress. Examples include a number of projects, such as the BMBF-funded (BMBF = German Federal Ministry of Education and Research) NanoCare project, in which nanomaterials which are relevant in terms of practical applications were examined under realistic and reproducible test conditions, from which concrete systematic data were then obtained. In this context, the Nanoderm project funded by the European Commission is no doubt one of the most frequently cited projects, and it was able to show that nano-TiO2 does not penetrate through undamaged skin. In addition, the projects CarboSafe (since 2008) and CarboLifeCycle (since 2010) have also been set up and started as part of the Innovation Alliance Carbon Nanotubes (Inno.CNT). Here, environmental aspects as well as emission and exposure scenarios are investigated among other things for carbon nanotubes (CNTs). The NanoCare and NanoNature projects tendered by BMBF, which look at issues relating to human toxicity and interactions between nanoparticles and the environment, have also recently started. In addition, there are numerous projects and activities at European level within the framework of the 6th (already completed) and 7th EU research framework programme which have now started up or recently put out to tender again.

The results of the industrial safety research will particularly also serve as the basis for registrations under the REACH system at the European Chemicals Agency ECHA.

Even if the current data available on environmental and human toxicity of numerous nanomaterials is already starting to reach satisfactory levels, this data is set to grow in further efforts carried out jointly between research scientists from academia and industry.

Alongside the research work, the aspect of dialogue between stakeholders on the benefits and challenges of nanotechnology is unique to Germany. Here, the cross-disciplinary work carried out by the internationally unique "NanoKommission" of the German Federal Government as part of the "NanoDialog" deserves particular mention. The open dialogue about the new technologies and new materials and the associated direct feedback of the corresponding requirements and expectations between the different interest groups helps to communicate a mutual and deeper understanding for the different requirements. As a result, the various aspects – opportunities and challenges alike – of nanotechnology can already be assessed more realistically.

In addition to the stakeholder dialogue, it is also very important to ensure that the research into the safety of nanotechnology is made transparent to the general public by making available the relevant information in a manner which can be readily understood. Work on this aspect was started via an Internet platform conducted as part of the NanoCare project. This will now be intensively continued in the DaNa project with support from the BMBF (German Federal Ministry of Education and Research). The DaNa project will compile existing knowledge and latest results from research projects into the safety of nanomaterials on the website "www.nanoobjects.info". It will attempt to provide interested members of the general public with objective and easy to understand information on the subject and to engage the wider public in a factual and well-informed discussion.

For research conducted into the safety of nanomaterials, this present paper offers a summary of the papers and work which have already been completed together with the results obtained, as well as a summary of the on-going activities and expected results. Here, the main focus of our considerations is on Germany, with a wider outlook on papers and results at European level. The necessary discussions about further topics and priorities in this field can only be conducted in a meaningful fashion on the basis of such appraisals (in a similar manner to the "NanoSafety-Cluster" which performed the same role for EU projects). To this extent, this summary is intended to provide effective support in the factual and well-informed discussion of the next steps which will be taken for research into the safety of nanomaterials.

II. Nanotechnology – Opportunities Presented by a New Technology

II.1. Introduction

The name "nanotechnology" is used to summarise a wide range of very varied innovations and developments. The feature which is common to all of these technologies is the comparatively small size of the mechanical or electronic components produced, as well as of objects made of very different chemical elements and compounds.

In the context of nanotechnology, the term "nanoscale" describes a size range from approximately 1 to 100 nanometres (nm) (ISO standard 27687). "Nano-objects" are materials with one, two or three dimensions at the nanoscale. "Nanoparticles" are nanoscalar in all three dimensions, while "nano-plates" are nanoscalar in one dimension and "nanorods" are nano-scalar in two dimensions. Nano-materials in the sense of this paper are fine-particle or fine-structured chemical substances with special technical properties. The dimensions of the particles or structures are typically between 1 and 100 nm.

For many years, the chemical industry has already been producing many products using particles or structures with dimensions ranging from around 1 to 100 nm. They can be found e.g. in the form of irregular particles, spheres, platelets, fibres, tubes or layers. The optical, electrical and magnetic properties of nanomaterials, but also their hardness, toughness and melting behaviour are in some cases very different to those of conventional materials. Use of these nanomaterials has made it possible to create completely new materials which are carefully customised to meet the specific requirements of a given application. Through addition of or coating with nano-objects, ceramics, metals and plastics can for example be developed which are scratch-resistant, non-reflective or water/grease/dirt repellent. Surfaces which kill bacteria or catalyse chemical reactions can also be made possible with nanomaterials.

Nano-objects are for example produced in a very hot gas flame or in the aqueous phase. Normally, so-called "primary" nano-objects are created in these production processes. These are usually highly reactive and react in just a few thousandths of a second with other primary nano-objects to form (secondary) aggregates. The constituent ingredients of the aggregates are chemically linked and will subsequently be either very difficult or impossible to separate, even during subsequent use of the product. In turn, the aggregates combine with other aggregates to form (tertiary) agglomerates; agglomerates of primary nano-objects are also possible. Agglomerates can be broken up again with the aid of suitable techniques.

As an aggregate has structures in the nanoscale range because it is formed through the combination of primary nano-objects, the "nano-properties" of these nano-objects often remain intact. New technical properties resulting from nanoscale structures and aggregate particle sizes above 100 nm are therefore not mutually exclusive.

Free nano-objects are not usually encountered in end user products – unless they are manufactured in this way for specific applications (e.g. in medicine), normally with considerable additional effort. The nanomaterials listed by way of example in the chapters below usually contain larger nanostructured particles, but these are not singular nano-objects.

As with all products, the individual toxicological properties with regard to humans and the environment also need to be investigated for nano-objects and nanomaterials if the potential risk of exposure (i.e. release into the environment or contact with humans) cannot be excluded. In this respect, the way in which the nanomaterials are used naturally plays a major role. General conclusions about the risks of nanomaterials cannot be drawn, since these risks depend on the different material properties and application conditions. Similarly to all other chemicals, the risks associated with nanomaterials have to be assessed on a case-by-case basis.

II.2. Nanomaterials in products which have already been launched on the market

Nanotechnology is characteristically diverse in its potential applications, and offers the potential for completely new products and applications right across the board in all industries. Some products based on nanotechnology are already highly evolved and – in some cases – have already been well-established in the marketplace for many years.
For more than a hundred years, **carbon black** has been used in the production of car tyres. These soot particles settle in the polymer network of rubber molecules. This strengthens the tyre mechanically and reduces wear.

Synthetic amorphous silica (amorphous silicon dioxide) has been used for decades in many different areas. In the case of this amorphous silica, relatively stable amorphous structures in the range of µm are built up already during the manufacturing process from the primary nanoparticles which are produced. Amorphous silica is used as strengthening agent in silicone rubber, as gelling agent in cosmetics and as flow improvers for the production of tablets. It also helps to establish the required viscosity in paints, adhesives and sealants. It is also the main ingredient in the production of high-performance high-temperature insulation materials and is used as an ultra-fine polishing agent in the microchip industry. In cleaning agents, amorphous silicon dioxide is used as a thickener and as an aid for changing surface properties. Water droplets on windows treated with these cleaning agents instantly wet the surface and combine together; for this reason the window does not steam up either. The advantage for the user is the reduced cleaning effort thanks to the improved or more consistent wetting properties.

With the aid of a sol containing **silicon dioxide** spheres with a diameter of 20 – 50 nm, anti-reflection coated toughened safety glass is produced for the protection of solar collectors and photovoltaic plants. Thanks to a thin coating of silicon dioxide, almost the full spectrum of sunlight which can be converted to electric energy is able to penetrate through the covering glass. Reflection is reduced from eight percent to two percent, which in turn allows the energy yield of solar systems to be significantly increased.

For a long time now, a specially coated type of paper has been on the market for inkjet printers. A porous layer made of **silicon dioxide nanomaterial** adsorbs the finely sprayed ink immediately, thus allowing much faster printing speeds.

Many types of sun cream contain **titanium dioxide** or **zinc oxide nanoparticles**. Since the oxide particles which provide the necessary protection against UV radiation are so small that they allow the more long-wave visible light to pass through, the cream remains transparent on the skin. However, the shorter-wave harmful UV radiation is reliably blocked.

Titanium dioxide nano-objects are also being used in innovative polyamide fibres to protect against harmful UV radiation. In this way, it is possible to achieve a sun protection factor of up to 80. Plastic spectacle lenses can be made more scratch-resistant thanks to a surface treatment with **zirconium dioxide** and titanium dioxide nano-objects which are encapsulated in **silicon dioxide**.

Nanoscale **titanium dioxide** is distributed in the glaze of innovative ceramic wall and floor tiles. This ingredient is photocatalytically active which, when exposed to light, forms reactive radicals with adhering substances like oxygen, water or organic substances which are capable of breaking down undesirable substances into e.g. toxicologically safe substances. When excited by UV radiation (e.g. sunlight), oxidation processes which are assisted by nanoscale titanium dioxide in facade paints or concrete surfaces can reduce air pollutants like nitrogen oxides. If visible light is used for the excitation (interior lighting is e.g. sufficient), then correspondingly equipped interior wall paints can eliminate volatile organic compounds (e.g. odours). Other self-cleaning effects can also be achieved with the aid of photocatalysis. The radicals which are formed can destroy bacteria, fungi, algae and moss and prevent the appearance of new agents.

Sanitary ceramics with a dirt-deflecting surface are also manufactured by adding nanoscale **aluminium oxide** or **silicon dioxide** to the glaze.

A newly developed lacquer contains **silver**-coated nano-**titanium dioxide** in order to able to kill bacteria and fungi. The lacquer, which is permeable to visible light, can be applied to metal, plastic or glass.

Silver nanoparticles are used as an anti-bacterial ingredient and to achieve self-cleaning effects in medical objects.

Sensors play a pivotal role in occupational health and safety, in the protection of the environment and during chemical processes. The electric conductance of **tin oxide, indium oxide and tungsten oxide nanomaterials** is altered in the presence of certain gases, which makes these materials ideal for use as sensors for gases or high molecular hydrocarbons. The sensitivity of this type of sensor depends greatly on the structure of its surface, which in turn is influenced by the fineness of the oxides which are used.

Ferrofluids (dispersions with nanoscale **iron oxide or other magnetic materials)** are used e.g. as liquid seals in fast-rotating computer hard disks.

Coated nanoscale **iron oxide** is used in magnetic resonance imaging as a medical contrast agent which is used to produce the images.

Nanoscale **palladium/platinum catalysts** are used in industrial hydrogenation applications. These are applied to a carrier material and have a large active surface.

Catalytic reaction steps are widely used in the chemical industry. With the aid of nanoscale catalysts, the consumption of raw materials can be significantly reduced, and side reactions as well as energy consumption can be minimised.

One particularly noteworthy example is **exhaust gas catalytic converters in motor vehicles**, which are used to reduce emissions of hydrocarbons, NO_x and carbon monoxide by 90%. Both in mobile and stationary applications, nanomaterial catalysts can lead to cleaner combustion processes and therefore to reduced emissions.

Polymer dispersions containing polymer particles in the order of magnitude from 10 nm to a few hundred 100 nm are used for example as binding agents in tile adhesives and wall paints, as well as finishing agents for paper, textiles and leather.

The material properties of **carbon nanotubes (CNT)** make them ideal for improving electrical conductance properties (nanowire) and for mechanical strengthening of plastics. First products have already been released in the leisure market, including ice hockey sticks, tennis rackets and golf clubs made of CNT reinforced materials. CNT based products are also used in the turbines of wind power stations: thanks to the reduced weight and increased mechanical load-bearing capacity of these materials, it has been possible to increase the span of the rotor blades, which in turn means that the wind energy can be converted more efficiently into electricity.

Polymer nanofibres have been used increasingly for years in filtration technology, for example for efficient air filtration in the automotive sector. In addition, high-tech textiles are currently being brought to market which offer improved breathability thanks to electrospun nanofibres without any loss of protection against wind and rain.

II.3. Nanomaterials in products which are in development or close to market entry

With the aid of a newly developed hydrophobic – i.e. water-repellent – nanoscale **silicon dioxide**, which can be dispersed in an organic solvent, micro and nanoscale layers can be applied to a range of different materials which provide the surface with a self-cleaning capability. For example, barrels, cups, pipettes and bowls can be coated on the inside so that they are always emptied without residue. Adding a coating of this new silicon dioxide formulation is a way to make many types of fabric both self-cleaning and water-repellent. Despite these properties, the fabric remains able to breathe.

Nanoscale **clay types** (“nano-bentonites”) can be used as fillers for polymers in the production of so-called “nanocomposite polymers”. An addition of up to 5% nanoscale clay can significantly improve the rigidity of polyolefins. In addition, shrinkage behaviour is reduced and thermostability along with resistance to chemicals are increased. In addition, the polymers which have been reinforced with clay are also more lightweight than comparable glass-fibre reinforced polymers. Nanocomposite polymers containing clay are more flame resistant and drip less during burning than unmodified polymers – and this means that they significantly reduce the risk of burn wounds. The qualities of technical plastics like polyamide can also be improved with nanoscale clay. Similarly to the polyolefins, improvements can be achieved in terms of shrinkage behaviour, thermostability and resistance to chemicals; in addition, it is also possible to manufacture parts with a smaller wall thickness. Applications include bumpers and interior trim parts on cars, as well as textiles and containers for chemicals .

Polymer composites with nanoscale **clay** are also used for the production of innovative films and foils. Depending on the matrix and composition, the different types of clay can also be used as barrier agents for water, oxygen or carbon dioxide (with applications e.g. in PET and polypropylene bottles, as well as generally in materials for the field of packaging).

A new adhesive is being developed with the aim of making it possible to establish an adhesive bond “at the push of a button” which can then subsequently be separated again. Here, pure and doped **iron oxide** nano-objects are suspended in the adhesive. With the aid of an alternating magnetic field, the tiny nano-objects heat up the adhesive, which hardens in the process. A stronger field and higher temperatures can then be applied to separate the substances again later on.

A lot of medical research is done with **iron oxide** nano-objects: loaded with active ingredients, the nano-objects are to be selectively directed through the body with the aid of a magnetic field until they reach their target organ and unload their freight. This work is still at the clinical research stage. A somewhat simpler version, in which magnetic iron particles are injected into tumours and heated with the aid of alternating magnetic fields so that the tumour is destroyed by the generated heat, is currently undergoing clinical trials.

Nanoscale **aluminium oxide** is incorporated as an additive in paints and lacquers which are designed to make furniture and laminate/PVC flooring more resistant to scratches. These special coatings are currently being investigated in terms of their market opportunities.

“Nanophosphors” are fluorescent particles with a particle size below 10 nm which are e.g. made up of **metal silicates, metal oxides, metal sulphates or metal phosphates**, into the crystal lattice of which e.g. individual **lanthanide** ions have been doped. The wavelength of the light emitted by these components depends on the type of lanthanide ions which are used. In future, it is hoped that nanophosphors will make testing of blood, saliva, urine and hair samples quicker and more reliable.

Carbon nanotubes (CNT) and **carbon nanofibres** can be used to modify the physical properties of plastics and can therefore open up new applications. For example, carbon nanotubes manufactured according to certain synthesis methods are good thermal conductors. However, they can also be manufactured to offer the properties of an electric conductor or semiconductor, and/or to display extremely high mechanical strength. Applications for conductive nanotubes and nanofibres include e.g. polymers with antistatic properties.

Carbon Nanotubes (CNT) can also have a positive effect on the physical properties of metals (e.g. aluminium). Innovative CNT/aluminium composites are almost as strong as steel, yet weigh only half as much. This makes them ideal for any type of application in which weight and energy consumption need to be reduced with lightweight design measures – for example in the automotive and aviation industries.

II.4. Research into new applications

Nanotechnology offers even greater potential for the introduction of new and specialised functionality in a wide range of different areas:

» Electronics and optics
» Health
» Energy
» Construction
» Environment

In the following, we have outlined a number of fields of research as examples with particularly great potential. The selection includes particle systems, coatings/layers and porous systems with dimensions in the range of nanometres.

Electronics and optics

Cost-effective **electronic components and sensors** which are constructed from nano-structured materials have excellent market chances. Research needs to be carried out here in relation to the composition and formulation of materials, as well as into the development of unconventional new production techniques, such as the inkjet method.

Long-term work is being carried out on the use of carbon nanotubes in a new generation of **computer chips**. The nanotubes are to be applied to a suitable plastic carrier and used as printed circuit board tracks and transistors. It is hoped that this will allow the production of chips with a storage density increased by a factor of a million compared to the current systems based on conventional silicon technology.

Research also still needs to be carried out into the production of **electrically conductive transparent coatings**, e.g. for flat-screen technology which can be generated with suitable surface structuring in the range of nanometres or by applying functionalised nano-objects.

In the field of **polymer electronics**, work is currently being carried out to test OLEDs (Organic Light Emitting Diodes) with layer thicknesses in the region of nanometres for applications in colour displays. Research is required here particularly into the lifetime of OLEDs, which to date has not been long enough for everyday use.

Health

The use of **active ingredient carriers** made of nanoscale materials may be able to bring about major progress in the development of therapeutic treatment for illnesses which were previously impossible or very difficult to treat, such as cancer, dementia or diabetes. In most cases, nano-objects are used here as the transport vehicles for active ingredients. This can allow the active ingredient to be protected against premature destruction or to improve its uptake in the body. Active ingredients which are difficult to dissolve can also be transported more effectively in this way. Various chemical changes to the surface of the nano-particle acting as active ingredient carrier open up a wide range of opportunities. Through the introduction of special biological functions, it is possible to achieve a selective release of the active ingredient at the target site, which allows the efficacy of the medicine to be increased and potential side-effects to be reduced. Nanoparticle transport systems may also be an option for overcoming the body's own barriers, for example the blood brain barrier, which would allow direct delivery of medication to the brain. Markers can also be applied to the nanoparticle active ingredient carriers which then make it possible to check the availability of active ingredients at the target site.

In addition, the coating of **implantation materials** with biocompatible or easy to clean surfaces complete with biocides or anti-adhesive properties is of great interest.

Energy

There is a demand for research to be carried out into the synthesis and formulation of nano-objects for **super capacitors** for short-term energy storage, e.g. in connection with solar cells. Furthermore, these super capacitors can also be used for short-term storage of large amounts of energy, e.g. in the automotive sector for the recuperation of kinetic energy.

Similarly, the use of nanomaterials is also expected to deliver improved **batteries as energy storage devices** (for example new types of lithium ion batteries) and more powerful **catalysts for fuel cells**.

Investigations are under way into so-called MOFs (metal organic frameworks) for the **storage of hydrogen** for fuel cells. With the aid of nanoporous networks made up of this type of structure, it is currently possible to store beyond 10% hydrogen by weight, albeit only at low temperatures and high pressures. The aim is to achieve a storage density of at least 6.5% by weight even at room temperature, as this would then start to make the application interesting for e.g. hydrogen-powered fuel cell vehicles.

Construction

Understanding of nanoporous systems is of great interest for new and significantly improved applications in insulation technology. For example, materials with pores in the nanometre range could lead to improved **insulation effects** on **insulating materials** for building construction, but also in vehicle and aviation construction.

Layers with a thickness in the range of nanometres can be used for **surface protection** and in order to introduce additional functionality into surfaces. The "lotus surface", i.e. a self-cleaning surface for walls or roof tiles, is one example of how nanotechnology has been successfully transferred from research into practice (although the lotus surface is actually made up of both micro and nano-structured components). However, attempts at using corresponding wall paint as a means of protecting buildings has shown that the technology still requires development (increased hardness of the surface layer, no formation of dirt streaks when it rains). Specifically with regard to the combination of physical and chemical nanotechnology (surface structuring and hydrophilisation/ hydrophobising) there is still great scope for improvement.

Environment

Nanotechnology and the use of nanomaterials offer the potential to significantly reduce the environmental impact of technical processes and products. In addition, the use of nanomaterials could also lead to innovations in other sectors, such as in the health, medical, automotive, aviation and energy sectors. A number of examples of positive environmental effects are listed below. In addition, there are many further references in the literature to promising fields for produced nano-objects.[2, 3, 4]

Active ingredients which are strengthened with **carbon nanotubes** and are subsequently both stronger and lighter than conventional materials may be able to save energy. This weight reduction can lead to reduced fuel consumption in **aircraft**, while the increased stability of **wind turbines** can lead to larger rotor blades with a higher energy yield.[5]

The efficiency of regenerative energy sources like **solar cells** can also be optimised with the use of nanomaterials. Nanomaterials can improve already efficient and cost-effective methods for energy conversion and energy storage (i.e. **fuel cells** and **lithium-ion batteries**) and thus lead to cars with reduced emissions and lower fuel consumption. In vehicles with conventional (diesel) engines, selective **catalytic converters** can help to reduce the **emission** of particles and gaseous pollutants.[6]

Water purification can be made more efficient with the aid of nanoscale or nano-structured materials. Investigations are currently under way into water purification methods which exploit the photocatalytic effects of nano-structured titanium dioxide to convert pollutants into non-toxic substances. Iron, other metals and diamond can also be used in nanoscale form for water purification – in some cases directly in the groundwater. In May 2010, work started here on the BMBF (German Federal Ministry of Education and Research) funded projects NAPASAN[7], Fe-NANOSIT[8] and NADINE[9] from the NanoNature programme.

Membranes and high-sensitivity **sensors** enable early detection of contaminants before any damage can occur. In addition, nanomaterials can also be used to replace (environmentally) toxic substances (i.e. flame retardants or toxic corrosion inhibitors).

1 http://www.rsc.org/ej/CS/2009/b802256a.pdf
2 "Nanotechnologien in der Schweiz: Herausforderungen erkannt" (Nanotechnologies in Switzerland: Challenges Identified), report on the publifocus dialogue process "Nanotechnologien und ihre Bedeutung für Gesundheit und Umwelt" (Nanotechnologies and their Significance for Health and the Environment), Zentrum für Technikfolgenabschätzung, TA-P 8/2006 d, Berne, 2006, ISBN no. 3-908174-25-2
3 NanoRoad SME: http://www.nanoroad.net
4 Nachhaltigkeitseffekte durch Herstellung und Anwendung nanotechnologischer Produkte (Sustainability effects resulting from the production and application of nanotechnology products), IÖW scientific journal series 177/04, Berlin
5 See: http://www.nanoobjects.info/cms/lang/en/Projekte/Inno.CNT/CarboAir
6 See :http://www.nanoobjects.info/cms/lang/en/Projekte/nano-scr
7 See: http://www.nanoobjects.info/cms/lang/en/Projekte/NAPASAN
8 See: http://www. nanoobjects.info/cms/lang/en/Projekte/Fe-NANOSIT
9 See: http://www.nanoobjects.info/cms/lang/en/Projekte/nadine

III. Questions and Answers on the Emission and Environmental/Human Toxicology of Nanomaterials

The large number of possible (and in some cases already realised) applications for nanotechnology show that it was necessary to give a high priority to carrying out investigations into possible risks. The standard procedure here is firstly to consider the potential hazard, i.e. to investigate whether it results in a health hazard if living organisms come into contact with nano-objects. Secondly, in order to be able to assess any risks for the population and e.g. for workers in the workplace, it is also necessary to know how likely it is that people will come into contact with the substance under consideration. The term used in this context is 'exposure'. Consequently, the overall risk depends both on the intrinsic risk and the exposure; the overall risk is usually defined as the product of intrinsic risk and exposure. If there is no intrinsic risk or no exposure then the overall risk is also zero.

We start in chapter III.1 by outlining the issues which need to be clarified and by sorting them into topical groups. In chapter III.2 we then list examples of the available answers, with the human and environmental toxicological aspects are summarised in subchapters III.2.1 and III.2.2. In chapter III.2.3 we also detail a number of projects which relate to the exposition of nano-objects.

III.1 Issues around nanomaterials

Back in 2003, DECHEMA and VCI established the joint working group "Responsible Production and Use of Nanomaterials" in Germany, which was made up of experts from industry and universities, particularly from Germany. The German regulatory authorities are also involved in the committee. The group discusses scientific results and best practice matters relating to safety aspects in the production and usage of nanomaterials. This working group drew up the list of priority topics of research listed below in 2005 and assigned the expected project results in the form of a table as shown in chapter III.2.1.3. For this paper, we have brought this relationship between projects and relevant issues addressed in the roadmap up to date (start of 2011).

III.1.1 Issues around human toxicology and safety research for nanomaterials

The key areas of research into the safety of nanomaterials are summarised in the list of high-priority research topics drawn up in 2005 by the DECHEMA/VCI working group Responsible Production and Use of Nanomaterials, which is shown on page 12. These choices are intended to help develop a deeper understanding of biological effects and mechanisms.

The points in this priorities list which are currently being dealt with or have already been dealt with in projects are marked in the table in section III.2.1.3 in the form of a roadmap which also lays out the relevant timing schedules.

III.1.2 Issues related to environmental safety aspects and to the release of nano-objects

The effects of free nano-objects on the environment need to be investigated at an early stage. Typical issues include:

- Can specific nano-objects damage particular areas of the environment?
- Are nano-objects released from sun creams, coatings and paints/lacquers into the environment?
- What is the environmental fate of nano-objects once they have been released? What impact do they have on water and soil? Are there any unforeseen effects?

The call for proposals[10] issued by the BMBF (German Federal Ministry of Education and Research) on 28.05.2008 in relation to the funding for the NanoNature programme contains a description of current issues in the area of the effects of synthetic nano-objects and nanomaterials on the environment[11]:

"The behaviour and the effects of synthetic nanoparticles and nanomaterials as well as of products with integrated functional nanomaterials in air, water and soil are to be investigated. To do this, the entire lifecycle of the nanoparticles or nanomaterials should be considered in terms of possible environmental toxicity. The following points are relevant here:

10 http://www.BMBF.de/foerderungen/12531.php

11 The text quoted here is a translation of the original text for the call for bids issued by the BMBF. Later on in the same year, DIN CEN ISO/TS 27687 was published as a pre-standard, containing a general definition of so-called nano-objects. Here, the term is used to describe the form of appearance of nanoscale objects. These are referred to as ‚nanoparticles" in the text of the call for bids. As a consequence, the term ‚nanoparticle' needs to be replaced with the current correct term ‚nano-objects' in the wording of the text.

List of high-priority research topics (human toxicology)

Toxicodynamics of nanoparticles (toxicological and physiological studies)

A.1 Investigation of the key parameters for the toxic effects (size, chemical composition, surface effects, morphology effects, ...)

A.2 Development and assessment of toxicological testing methods in terms of their suitability for the detection of different specific effects in the body under specific practical conditions, e.g. in the workplace. Identification and/or development of suitable (new) toxicological models (in vivo and in vitro), development of fast screening options for the investigation of toxicological effects already during the development phase.

A.3 Performance of toxicological studies for other materials than titanium dioxide and carbon black

A.4 Development of methods for reproducible production of aerosols in the nano-range for toxicological studies

Toxicokinetics and mechanistically-based studies

A.5 Transport of nano-objects into and through cells (crossing of organismic barriers – blood-brain barrier, placenta barrier etc.)

A.6 Mechanisms for the uptake of nano-objects via the skin

A.7 Mechanisms for the uptake of nano-objects via the lungs

Particles: Chemical analysis/production/release/ environmental relevance/disposal

A.8 Investigations into the real form of appearance (isolated nano-objects, agglomerates) and development of methods for recording the type and concentration of nanoparticles present in the workplace and in the environment

A.9 Stability of agglomerates under real technical conditions

A.10 Investigations into the real form of appearance (isolated nano-objects, agglomerates) in the body

A.11 Decomposition mechanisms for agglomerates in body fluids

» Development of structure-activity relationships (chemical lead determination), research into mechanisms of action and relevant action thresholds for environmental toxicological assessment

» Definition of parameters (e.g. size/surface area, crystalline structure, agglomeration behaviour, suspendability) which also take into account natural background exposure (distinction between synthetic/non-synthetic particles)

» Development of basic techniques and standard testing methods, establishing of reference materials, reproducibility and modelling

» Investigations into the functional stability and into the input of the particles into the environment (e.g. analysis of uptake mechanisms, input quantities, input forms, decomposition products and bioaccumulation)

» Mobility and transformation of the particles (e.g. bioavailability, persistence, metamorphosis, multi-generation effects, mixture toxicity, transport effects, long-term effects)

» Risk assessment on real matrices (e.g. confirmation of the results through environmentally relevant investigations, derivation and portability of regularities)"

The key points stated in the BMBF (German Federal Ministry of Education and Research) call for bids briefly summarise what is described in more detail in a listing produced by the working group "Responsible Production and Use of Nanomaterials". These points, which cover aspects relating to both environmental toxicology and exposure are listed below. The comparison in chapter III.2.2.3 of issues and corresponding projects which have been carried out also refers to this more detailed list.

Development of methodologies for testing effects

1) Development of globally harmonised methods for measurement of environmental impact and environmental toxicity (standardisation required)
   - Investigation in order to establish whether already existing methods can also be applied to the measurement of the environmental impact of nano-objects. If necessary, the test procedures need to be adapted, and the standard sample preparation methods (stirring, ultrasonic treatment, filtration etc.) need to be taken into account. The test methods should consider all relevant different types of solvents and all possible side effects, e.g. the interaction between nano-objects and the analysis unit.

   - Development of a standard procedure for determination of the particle size during the individual tests
2) Identification and preparation of reference nano-objects
   - Identification and definition of producers who can manufacture and supply the identified reference materials over a long period of time
   - Identification of the main parameters for the characterisation of the nano-form of a reference material

Substance properties

3) Determination of the agglomeration/segregation of specific nano-objects (stability of the nano-object), generalisation of the results in order to develop a standard model for agglomeration/segregation
   - Definition of the boundary conditions and the rate of agglomeration/segregation of certain nano-objects
   - Investigation of the thermodynamic principles which define the "phase transitions" and of the relevant physical properties of the objects
   - Investigations into whether or not the behaviour of nanoparticles/nano-objects is linked to their structural properties and whether or not the effects can be generalised
   - Comparison of the kinetics of standardised materials
   - Development of a standard procedure for defining the particle size during different tests
4) Aspects relating to the lifecycle (removal of dusts, recycling)
   - Investigations into the emission of nano-objects from products during their lifecycle
   - Performance of lifecycle assessments for different nano-objects or for one example of a relevant nano-object which is used in various applications
   - Investigation of direct environmental effects (e.g. release of nano-objects into the environment, stability of nanostructures) and indirect effects (e.g. waste disposal of dust, recycling, energy expenditure and carbon dioxide emissions)
   - Examination of the natural occurrence as a background value for specific materials (iron oxides, titanium dioxide, silicon dioxide) during measurements

Behaviour and fate in the environment

5) Determination of the mobility of persistent, technical nano-objects in surface waters, groundwater and soils (deposition, mobilisation, adsorption, desorption, kinetics, distribution, morphology) and the key parameters for definition of their mobility
   - Modelling of diffusion and dispersion of nano-objects in water, soil and air
   - Development of models which describe the interaction between nano-objects and other substances in relevant areas
   - Investigations to find out whether substances which are e.g. dissolved in organic media influence the stability of nanostructures and/or possible transport paths
6) Development of methodologies with the aid of which nano-objects in the environment (air, water, soil) can be identified and quantified at relevant (e.g. low) concentrations
   - These methods must be capable of distinguishing between naturally occurring and technically manufactured nano-objects.
7) Determination of the nano-object background exposure in the environment in order to be able to estimate the levels contributed from anthropogenic sources
   - The background exposure includes natural colloidal nano-objects and inadvertently released nano-objects (e.g. from combustion processes); all areas of the environment (soil, water, air) must be taken into account.
   - An intensive exchange of information with other projects which are already looking into the determination and/or quantification of nano-objects in the workplace or in living cells is recommended.
   - One interesting point could be the development of methods for on-site analysis (instruments which are easy to handle and transport and which allow results to be obtained quickly on-site)

Effects on organisms

8) Investigation of the uptake of persistent nano-objects by living organisms/microorganisms (in vivo and in vitro). Compilation of the information regarding toxicokinetics, deposition and accumulation of persistent nano-objects
   - The living organisms/microorganisms should be the ones which are also relevant for standard toxicity tests.
   - The investigations should consider different uptake routes and kinetics.

III.2 Answers: Nanomaterial risk research projects

Many of the open issues outlined above have been or are currently being investigated in projects, and many answers to these questions have already been obtained.

In the following, we aim to provide an insight into some of the ongoing and completed projects. We will also attempt to highlight the key results.

III.2.1 Overview of projects relating to research into the health-related safety of nanomaterials

In the following we have listed the national and international nanomaterial research projects in which the key area of research focuses on health-related matters. In the process, we have deliberately set out to present almost all of the projects carried out at national level, while we have restricted ourselves to just a selection of the international projects according to the availability of project results data.

III.2.1.1 German research projects

Name	Toxicology of particles from technical processes/synthetic nanoparticles
Funded by	Internal research program, Karlsruhe Research Centre, Institute of Toxicology and Genetics
Duration	Since approx. 1990
Task definition	» Research programme into the toxicology of particles from technical processes » Focus shifted since 1996 towards "synthetic nanoparticles"

Name	Cooperation between the Helmholtz Centre in Munich[12] and the US Environmental Protection Agency (EPA) on the subjects of "Fine and Ultrafine Particles" and "Allergies/Asthma"
Funded by	HMGU Munich (Helmholtz Centre Munich – German Research Center for Environmental Health) and US Environmental Protection Agency (EPA)
Duration	Since 1998
Task definition	» Epidemiological studies carried out in the past showed that tiny dust particles in the ambient air can severely impair our health. The consequences are particularly severe for the heart/circulatory system and for the lungs, but it is also possible that other organ systems like the central nervous system can be also be adversely affected. The primary sources for the fine dust identified by the scientists from GSF and from the USA were motor traffic in first place and industry in second. Another topic is the comparison between the different sources of the dusts in both countries. » However, knowledge about the sources is not enough by itself to draw any conclusions about potential health consequences for the population: Whether or not contact with fine dust will lead to a certain illness depends both on the toxicity of the particles and on the general health and age of the affected persons. Cardiovascular diseases afflict older people and people with existing pre-conditions in particular. The risks increase significantly above the age of 50. Cardiovascular disease is currently the most common cause of death.
Further information	http://www.helmholtz-muenchen.de/neu/aerosols/aktuelles1_en.php

12 Previously: GSF Research Centre for Health and the Environment

Name	NEW – Nanoparticle exposure in workplaces
Funded by	International Carbon Black Association and various industrial grant providers
Duration	2000 – 2010
Task definition	"Nanoparticle exposure in workplaces (NEW)" encompasses several individual projects at the IUTA Duisburg which address the investigation of the real morphology (isolated, agglomerated) of nano-objects and the development of methods for detecting the type and concentration of nano-objects in the workplace.
Results	» Kuhlbusch, T.A.J., Neumann, S., Fissan, H., Number size distribution, mass concentration, and particle composition of PM1, PM2.5 and PM10 in Bagging Areas of Carbon Black Production, *J. Occup. & Environ. Hygiene* 1, 660-671, 2004. » Kuhlbusch, T.A.J., Fissan, H., Particle Characteristics in the Reactor and Pelletizing Areas of Carbon Black Production, *J. Occup. & Environ. Hygiene* 3/10, 558 – 567, 2006. » Kuhlbusch, T.A.J., Fissan, H., Asbach, C., Nanotechnologies and Environmental Risks, in *Nanomaterials: Risks and Benefits*, Eds.: Linkov, I., Steevens, J., ISBN: 978-1-4020-9490-7, 233-243, 2009. » Kuhlbusch, T.A.J., Fissan, H., Asbach, C., Measurement and Detection of Nanoparticles Within the Environment, in *Nanotechnology: Volume 2: Environmental Aspects*. Ed. H. Krug, ISBN 978-527-31735-6, 229-266, 2008. » Further publications are currently in progress.

Name	NanoHealth – Nanoparticles and Health Network
Funded by	HMGU Munich (Helmholtz Centre Munich – German Research Center for Environmental Health) and US Environmental Protection Agency (EPA)
Duration	2000 – 2008
Task definition	» Research into the level of aerosol pollution in the environment with regard to human health » Project of six Helmholtz centres Targets: 1. Investigate in more detail the physical, chemical and biological properties of aerosol particles: » To comprehensively characterise aerosol particles from environmental aerosols, » To manufacture model particles for selected classes of environmental aerosols (e.g. soot particles with chemically varying envelope), » To determine the relevant exposure dose (chemical components and their mixtures, number, surface or mass of these particles). 2. Identify aerosol particles particularly of the environmental aerosol which represent a health risk: » To identify health-relevant model particles in 'in vitro' studies, » To establish susceptible animal models on which the reactions of the respiratory tract and the cardiovascular system are investigated in response to exposure to environmentally relevant concentrations of such model particles, » To explain reaction mechanisms, » To perform epidemiological studies with new dose and reaction parameters, » To perform a risk assessment for the inhalation of these environmental particles.
Further information	http://www.helmholtz-muenchen.de/neu/aerosols/index_en.php

Name	CFN – Centre for Functional Nanostructures (CFN) at KIT[13]
Funded by	DFG (German Research Foundation)
Duration	Since 7/2001
Task definition	Investigation of the transport of nano-objects into and through cells and of their passage through organ barriers (blood-brain barrier, placenta barrier etc.)
Further information	http://www.cfn.uni-karlsruhe.de

Name	INOS – Identification and Assessment of the Effects of Engineered Nanoparticles on Human and Environmental Health
Funded by	BMBF(German Federal Ministry of Education and Research)
Duration	01/2006 – 12/2008
Task definition	The project funded by BMBF evaluates potential health effects during the production, characterisation and processing of nanoscale powders. The work concentrates on ceramic and metallic particles like diamond, tungsten carbide, titanium dioxide, titanium carbonitride, cobalt, platinum, ceramic-metal mixtures, carbon nanotubes and carbon black. The cell toxicology investigations were carried out using a range of different human and animal cells like lung cells and intestinal epithelial cells, neurones and glial cells as cell lines or primary cells. The end points which were examined were the vitality, general stress response (such as changes in the protein expression), oxidative stress, inflammatory and immunomodulatory effects, genotoxicity, cell death etc.
Results	Microscale tungsten carbide-cobalt particles could be observed in scavenger cells (macrophages), and nanoscale tungsten carbide-cobalt particles could be observed in various different cell lines. Tungsten carbide-cobalt which has been absorbed into the body can be detected in the blood and is excreted in the urine. For these particles there are comparative tests with coarser particles. According to the investigations carried out to date, their is no evidence for these materials to support the conjecture that nanoparticles might have different action mechanisms to coarser particles on account of their size. The comparison of biological effects only displayed differences in terms of active strength. Likewise, tungsten carbide-cobalt proves to be toxic, but exposure occurs almost exclusively in the workplace, where suitable protection measures are implemented. Tungsten carbide particles are chemically inert and non-toxic, but suitable protection measures should still be implemented in the workplace.
Further information	http://www.nanopartikel.info/cms/Projekte/INOS

13 Karlsruhe Institute of Technology

Name	NanoCare – Health-related aspects of synthetic nanoparticles: Preparation of a general information and knowledge base as a foundation for innovative materials research
Funded by	BMBF(German Federal Ministry of Education and Research)
Duration	03/2006 – 07/2009
Task definition	» Investigation of key parameters which control toxic effects (size, chemical composition, surface effects, morphology) » Development and verification of methods for testing toxicity, taking into account their suitability; detection of various specific effects in bodies under practical conditions, e.g. in the workplace » Investigation of the toxicology of other materials than titanium oxide and carbon black » Development of methods for producing inhalable nanomaterial environments which are suitable for toxicity studies » Investigation of the stability of agglomerated nano-objects in bodily fluids
Results	» Toxicological data for eleven commercially available nanomaterials and their variations[14] » Standard Operating Procedures (SOPs) for the performance of investigations on nanomaterials Details: Toxicological studies carried out *in vivo* on rats via inhalation or via intratracheal instillation, in vitro with cell lines and ex vivo on alveolar macrophages showed: None of the investigated materials displayed severe effects in the sense that cells or animals displayed signs of acute toxicity or biological effects when treated with low doses. A good correlation was established in the comparison of the results from the *in vitro* studies and the *in vivo* studies. In a first approximation, the results of the *in vitro* studies are a good reflection of the *in vivo* investigations. The exposure experiments showed that: (1) eight of the tested materials displayed a tendency to release smaller particles from agglomerates under the effects of weak shearing forces, but eleven particles displayed no high dusting; (2) strong shearing forces (as e.g. occur during a leak) tend to increase the number of small particles, but this effect is highly dependent upon the particular material; (3) Models for particle dispersion in the workplace are good tools for estimating the behaviour and distribution of nanoparticles and the possible exposure in the workplace; (4) no nanoparticles or nano-objects resulting from the production process were detected during any of the measurements; (5) standardisation of measurements is required; in response to this, NanoCare developed Standard Operating Procedures (SOPs) for workplace exposure experiments; (6) innovative approaches like the “Karlsruhe Exposure System” allow direct measurements of biological effects in the workplace.
Further information	http://www.nanoobjects.info/cms/lang/en/Projekte/NanoCare

14 Summary of results: http://www.nanoobjects.info/files/content/dana/Dokumente/NanoCare/Publikationen/NanoCare_Final_Report.pdf

Name	TRACER – Toxicology and Health Risk Assessment of Carbon Nanomaterials
Funded by	BMBF(German Federal Ministry of Education and Research)
Duration	03/2006 – 02/2009
Task definition	The TRACER project assessed the cytotoxicity and biocompatibility of carbon nanotubes (CNT) and drew up a list of recommendations for safe manufacturing, processing and use of these products. The project was a cooperation between partners from universities and industry who worked together along various stages of the value creation chain.
Results	Within the framework of the project, new findings on the biocompatibility/toxicity and release of carbon nanomaterials were assessed with regard to the relevance of the test methods and evaluated in terms of their workplace and health relevance. In addition, recommendations were compiled with regard to handling and workplace safety where possible. A release of CNT can only be expected if the CNT material is present in the form of a dusty powder, but not during subsequent activities during the course of which CNT materials are processed into composite materials. The evaluation of the published data and experimental findings in this project clearly shows that it is not possible to draw up general effect characteristics which are valid for all carbon nanomaterials on the basis of the existing database. In accordance with the BAuA/VCI guidelines, attempts should therefore be made to minimise exposure until specific limits have been defined for carbon nanomaterials. Based on the results of this project, the recommendations in the BAuA/VCI guidelines for protection of workers when handling nanomaterials are also applicable to carbon nanomaterials.
Further information	http://www.nanoobjects.info/cms/lang/en/Projekte/Tracer

Name	^{44}Ti labelling of TiO_2 nanomaterials
Funded by	Internal research (University of Leipzig and HMGU Munich (Helmholtz Centre Munich – German Research Center for Environmental Health))
Duration	Since 06/2006
Task definition	Characterisation of nanomaterials via core quadrupolar interaction by means of perturbed γ-γ angular correlation and solubility studies in synthetic bodily fluids
Results	Results about the volume proportion and surface proportion of the core quadrupolar interaction signal, such as crystallinity and surface properties (porosity, H-mobility) are available for a range of TiO_2 nanomaterials (particles, tubes, wires).

Name	NanoExpo (BY) and NanoGesund
Funded by	Bayerisches Landesamt für Gesundheit und Lebensmittelsicherheit LGL (Bavarian Regional Office for Health and Food Safety LGL)
Duration	10/2007 – 10/2010
Task definition	Both of these projects focus on exposure to nanoobjects and the health significance of nanoobjects. In the process, both projects selectively investigated workplaces at which nano-objects are manufactured or processed, as well as "nano" products available on the market, in terms of exposure levels. If an exposure is determined, then investigations are carried out to assess whether or not this has negative health effects.
Results	» When nanoparticles are properly handled in production with full compliance with the relevant safety measures, no increased exposure has been observed to date. » Measurement of aerosol formation from consumer products: Pressurised gas sprays: strong formation of aerosols Pump sprays: reduced formation of aerosols » Short-term experimental exposure to laser printer emissions is technically quite feasible to set up, and an acceptable and sensitive investigation programme is also possible at the same time (main limitation: time requirements of modern, non-invasive techniques) » On healthy subjects in the pilot study, effects which would appear clinically relevant from a laser printer with a high emission of nanoparticles were not observed either in objective measured variables or in subjective variables. » Very slight indication of possible effects in alveolae and nasal mucosa
Further information	http://www.lgl.bayern.de/gesundheit/arbeitsplatz_umwelt/projekte_a_z/nano_arbeitsplaetze_verbraucher.htm (in German language)

Name	Investigation of the anti-oxidative responses of lung cells as the end point for the assessment of aerosols after exposure at the air-liquid boundary layer at KIT/ITG
Funded by	BfR (German Federal Institute for Risk Assessment)
Duration	11/2007 – 9/2011
Task definition	The aim of the work is to better understand the control mechanisms which define anti-oxidative responses after exposure to nanoparticles, in order to further develop the in vitro method for toxicological assessment of aerosols in terms of sensitive end points in lung cells. With the aid of the in vitro testing method, it is hoped that it will be possible to detect aerosols which are potentially harmful.
Results	Publication is in preparation.

Name	SPP (Schwerpunktprogramm) 1313 Bio-Nano-Responses – Biological responses to nanoscale particles
Funded by	DFG (German Research Foundation)/German university institutes
Duration	01/2008 – 12/2013
Task definition	» Molecular and cellular processes of nanoparticle toxicology in humans » Synthesis and characterisation of nanoparticles (metals, metal oxides, soot, polymers, quantum dots) » Surface properties of nanoparticles and agglomeration in biological media » Interactions between nanoparticles and biological systems (proteins, membranes, cells and cell nuclei) » Effects on biological functions
Results	Status seminars, intermediate reports and publications from the project members
Further information	http://www.spp1313.de/website/homepage/univer/startseite_83/en/en_startseite_univer_1.php

Name	LENA – Food safety in the use of nanoproducts and within the framework of nanotechnology applications
Funded by	Bayerisches Landesamt für Gesundheit und Lebensmittelsicherheit LGL (Bavarian Regional Office for Health and Food Safety LGL)
Duration	10/2009 – 10/2012
Task definition	Within the framework of the project, LGL aims to develop some basic principles for the analytical detection of nano-objects in the food sector. Here, the project is divided into two modules: » The first module investigates migration from food packaging. This looks at which materials are used for food packaging and assesses whether or not it is possible for nano-objects to migrate from the packaging to the food products. Furthermore, in the event that migration does take place, the conditions necessary for this to occur are also to be investigated (contact conditions between packaging and food product, type of nanomaterials and type of packaging). » In the second module, the chemical analysis and characterisation of nanomaterials in foodstuffs will be developed. Investigations here will include oral uptake and changes during the passage of nano-objects or “nano-products” through the gastrointestinal tract. In addition, it is hoped that the investigations will provide a clear answer on the subject of whether or not nano-objects are absorbed from the gastrointestinal tract into the organism.
Results	Project has not been finished yet; no results have been published to date.
Further information	http://www.lgl.bayern.de/gesundheit/arbeitsplatz_umwelt/projekte_a_z/ nano_lena_lebensmittelsicherheit.htm (in German language)

Name	NanoExpo (BMBF) – Nanobalance detector for personal measurements of nanoparticle exposure
Funded by	BMBF (German Federal Ministry of Education and Research)
Duration	05/2010 – 04/2013
Task definition	The aim of the "NanoExpo" project is to use materials with a microscale or nanoscale structure to develop highly sensitive, miniaturised components which can be used for personal nanoparticle analysis. They should take the form of a portable dosimeter which enables continuous and fast measurements of nanoparticle exposure. Nanoscale resonance scales will be used to make the particle mass directly measurable, in addition to which pre-selection will be used to further enable classification by size. This development is based on semiconductor nanotechnology. This technology has the potential for enabling cost-effective production of special sensors. It is intended that the device will subsequently subjected to operational tests at a workplace in a company which processes nanoparticles.
Results	Project has not been finished yet; no results have been published to date.
Further information	http://www.nanoobjects.info/cms/lang/en/Projekte/nanoexpo

Name	Carbon Black – Prediction of the human toxicological effects of synthetic carbon black nanoparticles
Funded by	BMBF(German Federal Ministry of Education and Research)
Duration	08/2010 – 07/2013
Task definition	The aim of the joint research project Carbon Black is to establish a testing system using test models of increasing complexity to examine the toxicological effects of modified and well-characterised carbon black nanoparticles (CBNP) in the respiratory tracts and the lung. The multi-stage testing system ranges from a simple cell culture model through tissue culture models to testing in the animal model with inhalation studies. **Subprojects** » SP 1: Carbon black nanoparticles (CBNP) specifically modified through gas phase synthesis *(Karlsruhe Institute of Technology)* » SP 2: Tox screening in vitro – inhalation in vivo *(Fraunhofer Institute for Toxicology and Experimental Medicine)* » SP 3: Effects of carbon black nanoparticles on the tracheal epithelium *(University of Lübeck)* » SP 4: Respiratory tract region specific effects of carbon black nanoparticles *(Borstel Research Centre)* » SP 5: Toxicological effects of CBNP on type II pneumocytes and Clara cells *(Philipps University Marburg)*
Results	Project has not been finished yet; no results have been published to date.
Further information	http://www.nanoobjects.info/cms/lang/en/Projekte/CarbonBlackProject

Name	NanoGEM – Nanostructured materials – Health, exposure and material properties
Funded by	BMBF (German Federal Ministry of Education and Research)
Duration	08/2010 – 07/2013
Task definition	NanoGEM is a consortium of university and private research institutions, industry representatives and authorities which aims to address open questions relating to sustainable development and risk assessment with specially adapted strategies. A comprehensive appraisal of the potential dangers associated with industrially relevant nanoparticles and nanomaterials will also be performed for the first time on further processed products. Special attention will be played to the aspect of biokinetics, i.e. the intake and distribution of nanoparticles in the human body as a function of size, structure and surface properties. Answers to questions relating to health and safety in the workplace and product safety during production, processing, use and disposal are to be obtained (among other things) with newly developed portable measuring devices. Within the framework of NanoGEM, the data required for a risk assessment for internal and external contact between nanoparticles and organisms will thus be compiled.
Results	Project has not been finished yet; no results have been published to date.
Further information	http://www.nanogem.de

Name	CarboTox – Development of screening methods for investigating the carcinogenic potential of carbon nanotubes
Funded by	BMBF (German Federal Ministry of Education and Research)
Duration	09/2010 – 08/2013
Task definition	CNT are used as fibres of different lengths and thicknesses, in stretched or in entangled form and with varying surface properties, and they can possibly cause adverse effects during uptake in the lung. The main goal of the project is to clarify whether individually present CNT fibres cause an asbestos-like biological effect. In addition, preferably safe testing methods are to be developed which will enable quick laboratory tests to assess the hazard potential of different CNT forms without the need for complex animal experiments. Once this type of reliable test method is available, it will be possible to identify safe CNT types already at an early phase of the product development process. This would allow the potential health risks during the production of CNT fibres and their processing into products or components which contain CNT could be significantly reduced. The significance of such testing methods is particularly high for reliably toxicity appraisals in industrial applications.
Results	Project has not been finished yet; no results have been published to date.
Further information	http://www.nanoobjects.info/cms/lang/en/Projekte/Carbotox

Name	NanoKon – Systematic assessment of the health effects of nanoscale contrast agents
Funded by	BMBF (German Federal Ministry of Education and Research)
Duration	10/2010 – 09/2013
Task definition	The aim of the project is to systematically investigate and assess the effects of innovative and new nanoparticles in particular on the gastrointestinal tract. The starting point for the investigations are nanoparticles with different surface properties and specific physical-chemical properties which define the interaction with individual body cells and entire organs.
Results	Project has not been finished yet; no results have been published to date.
Further information	http://www.nanoobjects.info/cms/lang/en/Projekte/NanoKon

Name	NanoMed – Toxicological characterisation of nanomaterials for diagnostic imaging in medicine
Funded by	BMBF (German Federal Ministry of Education and Research)
Duration	09/2010 – 08/2013
Task definition	The aim of the project is the development, characterisation and recording of internal exposure in humans to innovative nanoparticles with excellent imaging properties for computer tomography (CT) and magnetic resonance tomography (MRT), as well as the assessment of potential dangerousness. In addition, innovative test models will be developed which detect the nanoparticles in the cell in the laboratory and in animals.
Results	Project has not been finished yet; no results have been published to date.
Further information	http://www.nanoobjects.info/cms/lang/en/Projekte/nanomed

Name	Nano silver particles – Action mechanisms and investigation of their potential interaction with tissues, cells and molecules. Definition of their relevant incompatibility/intolerance potential.
Funded by	BMBF (German Federal Ministry of Education and Research)
Duration	10/2010 – 09/2013
Task definition	The aim of the project is to develop methods which will make it possible to distinguish between silver and dissolved silver in different medical material systems which contain nanosilver, in order to be able to then assign the effect/action accordingly. To do this, three different model systems such as implants/prostheses containing nanosilver with varying levels of nanosilver will be developed, the release of silver particles will be tested and the potential risks for humans will be investigated.
Results	Project has not been finished yet; no results have been published to date.
Further information	http://www.nanoobjects.info/cms/lang/en/Projekte/Nanosilberpartikel

III.2.1.2 European research projects

Name	NANODERM – Quality of skin as a barrier to ultra-fine particles
Funded by	EU
Duration	01/2003 – 06/2006
Task definition	Skin penetration of TiO_2 nanoparticles, in particular visualisation of putative transport paths and the *in vitro* and *in vivo* response of skin cells to contact with nanoparticles.
Results	» No penetration into vital tissue in healthy skin. » No diffusive transport, but mechanical rubbing-in instead. » Inhomogeneous distribution of sun protection creams on calluses. » Deep penetration in hair follicles, but not into vital tissue. » Large variation in the response of skin cells to contact with nanoparticles. The results confirmed that healthy skin forms an effective protective barrier.
Further information	http://www.uni-leipzig.de/~nanoderm

Name	Nanosafe – Risk Assessment in Production and Use of Nanoparticles with Development of Preventive Measures and Practice Codes
Funded by	EU
Duration	04/2003 – 06/2004
Task definition	The Nanosafe project assessed the risks in the production, handling and use of nano-objects in industrial processes and products, as well as in consumer goods. The available information about potential risks of nano-objects was collated, in order to evaluate the risks for employees and consumers and in order to provide regulatory measures and codes of conduct in order to prevent potential dangers.
Results	» Summary of the possible dangers associated with exposure to nanoparticles for employees and consumers (http://www.nanosafe.org/home/liblocal/docs/Nanosafe1_final_report.pdf) » Recommendations for regulator measures and codes of practice
Further information	Nanoparticles – known and unknown health risks. *Journal of Nanobiotechnology* 2 (12), 2004.

Name	NanoRisk – Integrated Foresight: The Safety and Risks of Carbon Nanotubes
Funded by	Swiss Federal Office for Public Health (BAG / FOPH), Swiss Federal Office for the Environment (BAFU / FOEN), Swiss Federal Office for Vocational Training and Technology – Development Agency for Innovation (BBTKTI), Empa Materials Science & Technology (CH)
Duration	02/2004 – 02/2007
Task definition	» Presentation of the current status of knowledge and the uncertainties regarding the safety of CNTs » Performance of a foresight study to investigate which potential problems could occur throughout the CNT lifecycle, so that appropriate prevention measures can already be implemented during the development stage. » *In vitro* studies on human lung cells
Results	Different materials and end points/parameters were tested in various biological systems. The main outcome was the description of the "Trojan horse" effect of nanoparticles, by means of which material is introduced into cells which would "normally" be excluded. It is possible that negative effects are caused in the cells as a result.
Further information	» *In vitro* cytotoxicity of oxide nanoparticles: comparison to asbestos, silica, and the effect of particle solubility. *Environmental Science & Technology* 40, 4374-4381. » Effects of combustion-derived ultrafine particles and manufactured nanoparticles on heart cells in vitro. *Toxicology* 253, 70-78. » Risk assessment of engineered nanomaterials: a survey of industrial approaches. *Environmental Science & Technology* 42, 640-646. » Reviewing the environmental and human health knowledge base of carbon nanotubes. *Environ Health Perspect* 115, 1125-1131. » Exposure of engineered nanoparticles to human lung epithelial cells: influence of chemical composition and catalytic activity on oxidative stress. *Environmental Science & Technology* 41, 4158-4163. » *In vitro* evaluation of possible adverse effects of nanosized materials. *Phys Stat Sol b* 243, 3556-3560. » Studying the potential release of carbon nanotubes throughout the application life cycle. *Journal of Cleaner Production* (2008) 16: 8-9. 927-937. » The degree and kind of agglomeration affect carbon nanotube cytotoxicity. *Toxicology letters* (168) 121-131.

Name	Canape – Carbon Nanotubes for Applications in Electronics, Catalysis, Composites and Nano-Biology
Funded by	EU
Duration	06/2004 – 05/2008
Task definition	» Development of CNT production techniques » Integration of biological and non-biological systems at nano level through surface modification and cell growth » CNTs in electronic applications » CNTs as catalysts (e.g. in the production of styrol) » Integration of nanotechnology in order to increase quality of living (safety and health aspects) » Moving the CMOS limits and preparation for post-CMOS » CNTs in fuel cells
Results	» A ISO109933-5 test is not sufficient in order to describe the toxicity » Effects are dependent on the cell type » Agglomeration has an influence on toxicity » C_{60}-toxicity is usually due to solvent contamination as a result of the production process » SWCNT influences cell adhesion and migration speed. » No evidence for CNT-induced apoptosis
Further information	» Reviewing the environmental and human health knowledge base of carbon nano-tubes. *Environmental Health Perspectives*, 115, 8, p 1125 – 1131. » The degree and kind of agglomeration affect carbon nanotube cytotoxicity. *Toxicology letters* (168) 121-131. » In vitro evaluation of possible adverse effect of nanosized materials. *Physica Status Solidi b* 243(13) 3556-60.

Name	Nanotox – Investigative Support for the Elucidation of the Toxicological Impact of Nanoparticles on Human Health and the Environment
Funded by	EU
Duration	02/2005 – 01/2007
Task definition	Analysis of information on the toxicological influence of nano-objects through the evaluation of information on » physical and chemical properties of different types of nano-objects and agglomerated nanocrystals, production and use, effects on human health incl. side effects, animal toxicology, environmental effects, mutagenicity/genotoxicity, metabolism/pharmacokinetics, standards for safe use, safe laboratory methods etc. » possible paths for the spreading of and contamination with nano-objects and agglomerated nanocrystals (e.g. adsorption, desorption, transport, aggregation, deposition, biological uptake).

Name	IMPART – Improving the understanding of the impact of nanoparticles on human health and the environment
Funded by	EU
Duration	02/2005 – 10/2008
Task definition	The objective of the IMPART project was to define the latest scientific and technological developments with regard to the risks of nano-object release in terms of human health and the environment. Guidelines and recommendations for future standards and release limits for nano-objects were drawn up.

Name	Nanosafe2 – Safe production and use of nanomaterials
Funded by	EU
Duration	04/2005 – 03/2009
Task definition	In the project, » toxicological test methods were developed and checked for detection under practical conditions, e.g. in the workplace, taking into account suitability and, various specific effects in the body, » the toxicity of other materials than titanium oxide and carbon black was studied, » methods were developed in order to reproducibly supply nanoscale aerosols for toxicological studies, » mechanisms were investigated by means of which nano-objects are absorbed in the lung, » the true morphology (isolated, agglomerated) of nano-objects was investigated, and methods were developed in order to detect the type and concentration of nano-objects in the workplace.
Results	Partial results of the Institute of Epidemiology of the HMGU: for the assessment, epidemiological and toxicological data were applied at a screening level of (1) occupational safety, (2) consumer safety and (3) environmental safety. Various health-related dose metrics (weight, number of particles and surface) were used to quantify potential risks and to compare the properties of these alternative risk assessment methods.
Further information	» Brüske-Hohlfeld, I., Peters, A., Wichmann, H.-E. (2005), Do Nanoparticles Interfere with Human Health? *GAIA, Ecological Perspectives for Science and Society* 14/1: 21– 23 » Brüske-Hohlfeld, I., Peters, A. (2008), Epidemiological Studies on Particulate Air Pollution. In: *Nanotechnology, Vol. 2: Environmental Aspects* (Hrsg.: Krug, H.F. et al.). Weinheim: Wiley-VCH, 267-290 (2008) » Hänninen, O., Brüske-Hohlfeld, I., Loh, M., Stoeger, T., Kreyling, W., Schmid, O. and Peters, A. (2009), Estimation of health risks and safety margins due to inhalation of ultrafine particles and nanoparticles in selected occupational, consumer and environmental settings, *Journal of Physics: Conference Series* 170, published online doi:10.1088/1742-6596/170/1/012031 » Hänninen, O., Brüske-Hohlfeld, I., Loh, M., Stoeger, T., Kreyling, W., Schmid, O., Peters, A. (2009), Occupational and consumer risk estimates for nanoparticles emitted by laser printers, *Journal of Nanoparticle Research*, published online doi: 10.1007/s11051-009-9693-z » http://www.nanosafe.org

Name	NEST Particle Risk – Risk Assessment of Exposure to Particles
Funded by	EU
Duration	06/2005 – 05/2008
Task definition	In the EU project "NEST Particle Risk", a study was set up on the health hazards caused by new types of objects like nanotubes or fullerene. The partners also developed methods for detecting and quantifying the presence of nano-objects in living tissue. The uptake and transport of nano-objects in living systems was investigated on the basis of the model system 'mouse'. The in vivo toxicity was also examined on the 'mouse' model; in vitro tests will be performed on cell cultures.
Results	» A single detection method cannot deliver a meaningful characterisation of nanoparticles. The optimum number of required detection methods should be selected on the basis of the nanoparticles being investigated. » Nanoparticle biokinetics: Translocation is dependent on the nanoparticle size and the surface charge. » *In vivo* pulmonary effects: Gold and C60 cause a weak, inflammatory reaction. » Genotoxicity: All nanoparticles displayed an increase in genotoxicity three hours after instillation during single-cell electrophoresis on BAL cells. » Release and risk assessment: Identification and integration of the most important lines of evidence (LoE) in order to assess the possible causes of the risk due to nanoparticles according to the weight of evidence (WoE) approach. » Evaluation of a risk index for nanoparticles on the basis of the determined lines of evidence, taking into account the actual/potential applications of nanoparticles and the human groups affected by the exposure. » Ranking of hazardous nanoparticles

Name	NANOTRANSPORT – The Behaviour of Aerosols Released to Ambient Air from Nanoparticle Manufacturing – A Pre-normative Study
Funded by	EU
Duration	09/2006 – 04/2008
Task definition	The aims of the "NANOTRANSPORT" project were to investigate the behaviour of aerosols in the ambient air in workplaces in companies which manufacture or process nanomaterials, to define realistic test conditions with regard to the characterisation of the aerosols which are to be used for the nanotoxicological investigations, as well as the testing and certification of technical monitoring systems (fine dust measuring devices, measuring devices for emissions and technical gases). It was expected that the findings gained during this project would assist with the development of standardised test aerosols.
Results	» Significant changes take place in the nanoaerosols over time: their average size increases, while their concentration decreases. » Natural background aerosols are scavengers for nanoparticles. » The time scale for the changes in terms of the aerosol size depends on the concentration and the primary size of the nanoparticles and the background aerosol – it can range from a few minutes to half an hour. » The physical/chemical properties of nanoparticles change after emission. » The filtering efficiency for primary nanoparticles ⇠ 80 nm is normally sufficiently high; however, their agglomerates are in the Most Penetrating Particle Size (MPPS) range between 80 and 200 nm.

Name	DIPNA – Development of an integrated platform for nanoparticle analysis to verify their possible toxicity and the eco-toxicity
Funded by	EU
Duration	11/2006 – 10/2009
Task definition	The project pursued the following aims: » the development of a cell model for nano-object induced immunotoxicity in order to explain the in vivo findings, » the performance of in vitro tests to investigate the interaction between synthetic nano-objects and body cells, » the identification of key mechanisms in the particle-cell interaction and » the development of cell models and their application in field trials.
Results	» The effects of cobalt, gold, cerium and iron oxide nanoparticles in liquid suspension and in a dry state on various types of human defence cells were investigated in vitro in order to identify biomarkers for nanotoxicity and design assays. » Under acute exposure, most of the tested nanoparticles triggered no relevant toxic effects, neither did they influence selected inflammatory parameters in human leucocytes and the lung or the intestinal mucosa epithelial cells. » Cell growth inhibition and production of reactive oxygen species was only observed for cobalt nanoparticles and was probably caused by the release of cobalt ions and not by a nanoparticle-cell interaction. » An automated module system comprising a monitored incubator, a fluid system and optical detector units was designed and built for nanotoxicological field investigations. » A system was developed for repeated atomisation of dry nanoparticles in air.

Name	NANOSH – Inflammatory and genotoxic effects of engineered nanomaterials“
Funded by	EU
Duration	11/2006 – 04/2010
Task definition	The aim of this project is to understand the relationship between the physical-chemical properties of nano-objects (size and surface chemistry) and their possible toxic potential for various organs of the human body (lung and digestive tract, liver, kidneys, immune system). This was to be achieved not only with the aid of conventional toxicological methods, but also through innovative methods like toxicogenomics. Within the framework of the project, binding conclusions are to be arrived at regarding the possible health risks posed by nano-objects. Alongside the results on exposure of the population to nano-objects, it was hoped that results would also be obtained on the exposure of employees to nano-objects.

Name	NANOINTERACT – Development of a platform and toolkit for understanding interactions between nanoparticles and the living world
Funded by	EU
Duration	01/2007 – 12/2009
Task definition	The targets of the "NANOINTERACT" project were to investigate and describe the interactions between nano-objects and living cells: starting with the uptake of the particles into the body, via transport, the nature of the uptake process and the accumulation of nanoparticles in tissues and organs right up to complete explanation of the interaction between nano-objects and individual cells. In the process, primary efforts focused on: » possibilities for cell penetration of nano-objects » dependency of cell penetration on the properties of the nano-objects (size, shape and surface)
Results	The project did not yield any newly defined dangers (due to nanoscale elements alone) for nano-objects, but it does point to a number of problems which require further investigation, in particular with regard to the necessity of a test to examine the appropriateness of some of the established OECD (and other) tests for the chemical toxicity of nano-objects in order to assess their toxicity. NanoInteract published over 40 publications on various aspects of the interactions between nano-objects and living systems, including the round robin studies for the validation of test methods. In addition, 2 books are also in preparation.

Name	NanoSafe Textiles
Funded by	TVS Textilverband Schweiz und Empa (CH)
Duration	2007 – 2009
Task definition	The aim of this project was to take stock of the development trends of current and future applications for synthetic nano-objects in textiles and to highlight potential risks along the life cycle of textile applications.
Results	Translation of original German quotes from the final report (status: March 2010) relating to textiles modified with nano-objects: "In terms of health and based on current knowledge, we would generally classify nanoparticles made of silver (Ag), titanium dioxide (TiO_2) and silicon dioxide (SiO_2) as safe." "Nanoparticles made of aluminium(hydr)oxide and montmorillonite cannot be assessed at present, as there are simply no studies available for these two materials." "In the case of carbon nanotubes, any assessment is also difficult, as the variability of the materials used is very large, as a result of which no direct comparison of all results is possible. There are indications here both of toxic effects and of their safety, so it appears that we will not be able to draw any reliable conclusions until a systematic investigation of this material has been performed." "By contrast, zinc oxide and carbon black are two materials which have been proven to be capable of triggering reactions in biological systems. For example, they are able to penetrate tissue barriers, and there is indication of a DNA-damaging effect. However, it must also be emphasised in these cases that these effects only occur in a very high concentration range. These concentrations are rarely significant even for worst-case-scenarios, as a result of which the situation cannot be described as alarming or risky."
Further information	http://www.swisstextiles.ch/news/allenews/archive-2010/?id=10756 (in German language)

Name	AntiCarb – Monoclonal ANTIbody-targeted CARBon nanotubes against cancer
Funded by	EU
Duration	03/2008 – 08/2011
Task definition	The objective of ANTICARB is the design and development of carbon nanotube antibody elements. These are being investigated as novel, combinatory therapeutic/diagnostic aids for cancer treatment.
Results	The final report is currently being prepared. Links to project-related publications can be found on the website.
Further information	http://anticarb.org

Name	NanoTEST – Development of methodology for alternative testing strategies for the assessment of the toxicological profile of nanoparticles used in medical diagnostics. To study specific and nonspecific interactions of NP with molecules, cells and organs and to develop in vitro methods which can identify the toxicological potential of nanoparticles.
Funded by	EU
Duration	04/2008 – 09/2011
Task definition	The aim of the EU project NanoTEST is to develop new and alternative test methods and strategies for the characterisation of nanomaterials. In particular, test methods for in vitro and in vivo systems are to be developed/refined in order to improve the risk assessment of nanomaterials.
Results	The project ran until September 2011, and no results have been published yet.
Further information	http://www.nanotest-fp7.eu

Name	NANOMMUNE – Comprehensive Assessment of Hazardous Effects of Engineered Nanomaterials on the Immune System
Funded by	EU
Duration	09/2008 – 08/2011
Task definition	In the NANOMMUNE project, the influence of synthetic nanomaterials on the immune system and their potentially negative effects on health are being investigated. The toxic potential of selected nanomaterials (gold, silver, cerium oxide, iron oxides and others) is being determined.
Results	The final report is currently being prepared. Initial findings include: » Innovate biomedical applications for CNTs are possible under the conditions of careful, controlled biological decomposition. » The consortium is compiling a NANOMMUNE quality handbook in which the standard operating procedures (SOPs) resulting from the project are summarised. The handbook will be freely available.
Further information	http://www.nanommune.eu (with links to the project publications)

Name	IANH – International Alliance for NanoEHS Harmonisation
Funded by	Freiwillig, ohne spezielle Förderung
Duration	09/2008 – ca. 2012
Task definition	» Methods for characterisation and for determination of the biological effects of nanomaterials » Round robin tests on biological effects
Results	This voluntary alliance is still ongoing.
Further information	http://www.nanoehsalliance.org

Name	NanoImpactNet – European Network on the Health and Environmental Impact of Nanomaterials
Funded by	EU
Duration	04/2008 – 03/2012
Task definition	A network which » promotes cooperation between projects » communicates results to stakeholders and feeds back their requirements to the researchers » helps to implement the "EU Action Plan for Nanotechnology"
Results	Preparation and dissemination of harmonised protocols for standardised tests
Further information	http://www.nanoimpactnet.eu

Name	POCO – Carbon Nanotube Confinement Strategies to Develop Novel Polymer Matrix Composites
Funded by	EU
Duration	11/2008 – 10/2012
Task definition	Determination of the health aspects of (functionalised) MWCNT (Multiwalled Carbon Nanotubes) with the aid of cell cultures
Results	» Materials are currently being supplied. » Effects on simple single cell type systems and complex multiple cell type systems
Further information	http://www.poco-project.org

Name	MAGISTER – MAGnetIc Scaffolds for in vivo Tissue EngineeRing
Funded by	EU
Laufzeit	12/2008 – 11/2012
Aufgabenstellung	Determination of the health aspects of (functionalised) magnetic nano-objects and scaffolds function-alised with magnetic nano-objects with or without magnetic fields by means of cell cultures
Ergebnisse	» Effects on simple single cell type systems and complex multiple cell type systems

Name	NeuroNano – Do nanoparticles induce neurodegenerative diseases? Understanding the origin of reactive oxidative species and protein aggregation and misfolding phenomena in the presence of nanoparticles
Funded by	EU
Duration	02/2009 – 01/2012
Task definition	NeuroNano addresses the following issue: "Do nano-objects induce neurodegenerative diseases?" The project aims to understand the origin of reactive oxidative species, protein aggregation and misfolding phenomena in the presence of nano-objects.
Results	Project has not been finished yet; no results published to date.
Further information	http://www.neuronano.eu

Name	InLiveTox – Intestinal, Liver and Endothelial Nanoparticle Toxicity Development and evaluation of a novel tool for high-throughput data generation
Funded by	EU
Duration	05/2009 – 04/2012
Task definition	The aim of InLiveTox is to develop an alternative method to animal testing which can equally effectively assess the danger of nano-object intake. In addition, the basic toxicity of specific particles is to be initially determined individually in each cell type, then in combination with other particles.
Results	Project has not been finished yet; no results published to date.
Further information	http://www.napier.ac.uk/randkt/rktcentres/nanosafety/research/people/Pages/InLiveTox.aspx

Name	ENPRA – Risk assessment of engineered Nanoparticles
Funded by	EU
Duration	05/2009 – 10/2012
Task definition	The ENPRA project addresses the development and implementation of a new integrative approach for the risk assessment of nano-objects.
Results	Project has not been finished yet; no results have been published to date.
Further information	http://www.enpra.eu

Name	VIGO – Bewertungssystem für biologische Wirkungen von Nanomaterialien
Funded by	CCMX, CH
Duration	2010 – 2013
Task definition	Standardisation of methods for the 4 most important biological end points: vitality, inflammation, genotoxicity, oxidative stress
Results	Project has not been finished yet; no results have been published to date.
Further information	http://www.ccmx.ch/organisational-structure/matlife/thematic-research-areas.html

Name	NANOGENOTOX – Towards a method for detecting the potential genotoxicity of nanomaterials
Funded by	Mitgliedsstaaten/EU (Joint Action)
Duration	03/2010 – 02/2013
Task definition	Investigation of the genotoxicity of selected nanomaterials. 15 different modified nanomaterials will be investigated on the basis of silicon dioxide (SiO2), titanium dioxide (TiO2) and carbon nanotubes (CNT). The aim of the project is to make available further information on the effects of the investigated nanomaterials on humans and the environment by collating relevant and reliable data. The following work (among others) will be performed in the process: » Distinguishing specific dangers in relation to the physical and chemical parameters of the nano-material » Establishing a correlation between genotoxicological data from in vivo and in vitro experiments and further information on the bioaccumulation of nanomaterials through identification of the destination organs.
Results	Project has not been finished yet; first publications are available on the website.
Further information	http://www.nanogenotox.eu (with links to the project publications)

The projects[15] listed here have been assigned to the questions raised in chapter III.1.1 and sorted chronologically in the roadmap on the following pages.

15 Further EU projects can also be found here: http://cordis.europa.eu/nanotechnology/src/safety.htm

III.2.1.3 Roadmap for human toxicology and safety research for nanomaterials

Projects based on the high-priority (DECHEMA/VCI) research topics							
Priority and description		2000		2001		2002	
		1st	2nd	1st	2nd	1st	2nd
1	Investigation of the key parameters for the toxic effects (size, chemical composition, surface effects, morphology effects, ...)	=> seit 1998: GSF/EPA-cooperation	GSF/EPA-cooperation	GSF/EPA-cooperation	GSF/EPA-cooperation	GSF/EPA-cooperation	GSF/EPA-cooperation
2	Development and assessment of toxicological testing methods in terms of their suitability for the detection of different specific effects in the body under specific practical conditions, e.g. in the workplace. Identification and/or development of suitable (new) toxicological models (*in vivo* and *in vitro*), development of fast screening options for the investigation of toxicological effects already during the development phase.						
3	Performance of toxicological studies for other materials than titanium dioxide and carbon black	FZK-ITG: internal research programme					
4	Development of methods for reproducible production of aerosols in the nano-range for toxicological studies	NanoHealth	NanoHealth	NanoHealth	NanoHealth	NanoHealth	NanoHealth
5	Transport of nano-objects into and through cells (transgression of organismic barriers – blood-brain barrier, placenta barrier etc.)	FZK-ITG: internal research programme GSF/EPA-cooperation	GSF/EPA-cooperation	GSF/EPA-cooperation	GSF/EPA-cooperation CFN	GSF/EPA-cooperation CFN	GSF/EPA-cooperation CFN
6	Mechanisms for the uptake of nano-objects via the skin						
7	Mechanisms for the uptake of nano-objects via the lungs	GSF/EPA-cooperation	GSF/EPA-cooperation	GSF/EPA-cooperation	GSF/EPA-cooperation	GSF/EPA-cooperation NanoHealth	GSF/EPA-cooperation NanoHealth
8	Investigations into the real form of appearance (isolated nano-objects, agglomerates) and development of methods for recording the type and concentration of nanoparticles present in the workplace and in the environment	GSF/EPA-cooperation NEW	GSF/EPA-cooperation NEW	GSF/EPA-cooperation NEW	GSF/EPA-cooperation NEW	GSF/EPA-cooperation NEW	GSF/EPA-cooperation NEW
9	Stability of agglomerates under real technical conditions						
10	Investigations into the real form of appearance (isolated nano-objects, agglomerates) in the body						
11	Decomposition mechanisms for agglomerates in bodily fluids						

Abbreviations used in the roadmap:

Ag-NP: Nanosilver particles (BMBF), aap Biomaterials GmbH
ASO: Aerosol synthesis of metal oxides, University of Duisburg-Essen
DFG: SPP (Schwerpunktprogramm) 1313 of the German Research Community
CFN: DFG Centre for Functional Nanostructures, Karlsruhe
KIT: R&D Institute for Toxicology and Genetics of the KIT (Karlsruhe Institute of Technology, up to 2009 FZK: Research Centre Karlsruhe)

2003		2004		2005		2006	
1st	2nd	1st	2nd	1st	2nd	1st	2nd
Nanosafe GSF/EPA- cooperation	Nanosafe GSF/EPA- cooperation	Nanosafe NanoRisk Canape GSF/EPA- cooperation	NanoRisk Canape GSF/EPA- cooperation	Nanotox NanoRisk Canape GSF/EPA- cooperation	Nanotox NanoRisk Canape GSF/EPA- cooperation	INOS NanoCare KIT HMGU Nanotox Tracer NanoRisk Canape	INOS NanoCare KIT HMGU Nanotox Tracer CellNanoTox NANOSH NanoRisk Canape
					Nanosafe2	INOS Nanosafe2 HMGU	INOS Nanocare KIT Nanosafe2 HMGU CellNanoTox DIPNA
		NanoRisk Canape	NanoRisk Canape	NanoRisk Canape	KIT Nanosafe2 Particle Risk NanoRsik Canape	INOS Nanocare KIT Nanosafe2 HMGU Particle Risk NanoRisk Canape	INOS Nanocare KIT Nanosafe2 HMGU Particle Risk NanoRisk Canape
NanoHealth	NanoHealth	NanoHealth	NanoHealth	NanoHealth	KIT ASO Nanosafe2 NanoHealth	Nanocare KIT ASO HMGU Nanosafe2 NanoHealth	Nanocare KIT ASO Nanosafe2 HMGU NANO-TRANSPORT NanoHealth
GSF/EPA- cooperation CFN	GSF/EPA- cooperation CFN	NanoRisk GSF/EPA- cooperation CFN	NanoRisk GSF/EPA- cooperation CFN	NanoRisk GSF/EPA- cooperation CFN	CFN Nanosafe2 Particle Risk NanoRisk GSF/EPA- cooperation	CFN Particle Risk Nanosafe2 INOS NanoRisk	CFN Particle Risk Nanosafe2 INOS DIPNA NanoRisk
Nanoderm	Nanoderm	Nanoderm	Nanoderm	Nanoderm	Nanoderm	Nanoderm	
GSF/EPA- cooperation NanoHealth	GSF/EPA- cooperation NanoHealth	NanoRisk GSF/EPA- cooperation NanoHealth	NanoRisk GSF/EPA- cooperation NanoHealth	HMGU LS NanoRisk GSF/EPA- cooperation NanoHealth	HMGU LS Nanosafe2 NanoRisk GSF/EPA- cooperation NanoHealth	HMGU NanoCare Nanosafe2 LS NanoRisk NanoHealth	HMGU Nanocare LS Nanosafe2 CellNanoRisk NANOSH NanoRisk NanoHealth
Nanosafe GSF/EPA- cooperation NEW	Nanosafe GSF/EPA- cooperation NEW	Nanosafe GSF/EPA- cooperation NEW	GSF/EPA- cooperation NEW	Nanosafe2 GSF/EPA- cooperation NEW IMPART	Nanosafe2 GSF/EPA- cooperation NEW IMPART	Nanosafe2 NEW IMPART HMGU	Nanosafe2 NEW IMPART HMGU NANOSH
						NanoCare HMGU	Nanocare HMGU
						HMGU NEW Nanosafe2 NanoCare	HMGU NEW Nanosafe2 Nanocare
						Nanocare INOS	Nanocare INOS UniL

HMGU: Helmholtz Centre Munich, German Research Centre for Health and the Environment
LS: Development of a lung simulator, IUTA, Duisburg
NEW: Nanoparticle exposure in the workplace, IUTA, Duisburg
UniL: University of Leipzig

Projects based on the high-priority (DECHEMA/VCI) research topics

Priority and description		2007		2008		2009	
		1st	2nd	1st	2nd	1st	2nd
1	Investigation of the key parameters for the toxic effects (size, chemical composition, surface effects, morphology effects, …)	INOS Nanocare KIT HMGU Nanotox Tracer CellNanoTox NANOSH EMPA NanoRisk Canape	INOS NanoCare KIT HMGU Nanotox Tracer CellNanoTox NANOSH EMPA Canape	NanoCare INOS TRACER CarboSafe CellNanoTox NANOSH EMPA KIT HMGU Canape	NanoCare INOS TRACER CarboSafe CellNanoTox NANOSH EMPA KIT HMGU IANH	NanoCare TRACER CarboSafe CellNanoTox NANOSH KIT HMGU IANH InLiveTox	NanoCare CarboSafe CellNanoTox AnNa NanoLang NANOSH KIT HMGU IANH InLiveTox
2	Development and assessment of toxicological testing methods in terms of their suitability for the detection of different specific effects in the body under specific practical conditions, e.g. in the workplace. Identification and/or development of suitable (new) toxicological models (*in vivo* and *in vitro*), development of fast screening options for the investigation of toxicological effects already during the development phase.	INOS Nanocare KIT Nanosafe2 HMGU CellNanoTox DIPNA NanoInteract EMPA	INOS Nanocare KIT Nanosafe2 HMGU CellNanoTox DIPNA NanoInteract EMPA	INOS Nanocare KIT Nanosafe2 HMGU CellNanoTox DIPNA NanoInteract EMPA	INOS Nanosafe2 CellNanoTox DIPNA NanoInteract NANOMMUNE EMPA KIT HMGU NanoImpactNet	Nanosafe2 CellNanoTox DIPNA NanoInteract NANOMMUNE KIT HMGU NanoImpactNet InLiveTox	CellNanoTox DIPNA NanoInteract NANOMMUNE KIT HMGU NanoImpactNet InLiveTox
3	Performance of toxicological studies for other materials than titanium dioxide and carbon black	INOS Nanocare KIT Nanosafe2 HMGU Particle Risk EMPA NanoRisk Canape Nanosafe Tex.	INOS Nanocare KIT Nanosafe2 HMGU Particle Risk EMPA Canapoe Nanosafe Tex.	Nanocare Nanosafe2 HMGU Particle Risk INOS CarboSafe NanoTEST EMPA KIT Canape AntiCarb POCO MAGISTER Nanosafe Tex.	Nanosafe2 Particle Risk INOS CarboSafe NanoTEST EMPA KIT HMGU AntiCarb POCO MAGISTER Nanosafe Tex.	Nanosafe2 CarboSafe NanoTEST KIT HMGU AntiCarb POCO MAGISTER Nanosafe Tex.	CarboSafe AnNa NanoLang NanoTEST KIT HMGU AntiCarb POCO MAGISTER Nanosafe Tex.
4	Development of methods for reproducible production of aerosols in the nano-range for toxicological studies	Nanocare KIT ASO Nanosafe2 HMGU NANO-TRANSPORT NanoHealth	Nanocare KIT ASO Nanosafe2 HMGU NANO-TRANSPORT NanoHealth	Nanosafe2 NANO-TRANSPORT KIT HMGU NanoHealth	Nanosafe2 KIT HMGU NanoHealth	Nanosafe2 KIT HMGU	KIT HMGU
5	Transport of nano-objects into and through cells (transgression of organismic barriers – blood-brain barrier, placenta barrier etc.)	CFN Particle Risk Nanosafe2 INOS DIPNA NanoRisk	CFN Particle Rsik DFG Nanosafe2 INOS DIPNA	CFN Particle Risk DFG INOS Nanosafe2 DIPNA NanoTEST EMPA POCO MAGISTER	CFN Particle Risk DFG INOS Nanosafe2 DIPNA NanoTEST EMPA KIT POCO MAGISTER	CFN Nanosafe2 DFG DIPNA NanoTEST KIT POCO MAGISTER NeuroNano InLiveTox	CFN DFG DIPNA NanoTEST KIT POCO MAGISTER NeuroNano InLiveTox
6	Mechanisms for the uptake of nano-objects via the skin						
7	Mechanisms for the uptake of nano-objects via the lungs	HMGU Nanocare LS Nanosafe2 CellNanoTox NanoInteract NANOSH NanoRisk NanoHealth	HMGU Nanocare LS Nanosafe2 CellNanoTox NanoInteract NANOSH NanoHealth	Nanocare LS Nanosafe2 CellNanoTox NanoInteract NANOSH HMGU NanoHealth	Nanocare LS Nanosafe2 CellNanoTox NanoInteract NANOSH HMGU NanoHealth	Nanosafe2 CellNanoTox NanoInteract NANOSH HMGU	CellNanoTox NanoInteract NANOSH HMGU
8	Investigations into the real form of appearance (isolated nano-objects, agglomerates) and development of methods for recording the type and concentration of nanoparticles present in the workplace and in the environment	Nanosafe2 NEW IMPART HMGU NANOSH	Nanosafe2 NEW IMPART HMGU NANOSH NanoExpo(BY) NanoGesund	Nanosafe2 NEW IMPART DFG CarboSafe NANOSH NanoExpo(BY) NanoGesund HMGU	Nanosafe2 NEW IMPART DFG CarboSafe NANOMMUNE NANOSH NanoExpo(BY) NanoGesund HMGU	Nanosafe2 NEW DFG CarboSafe NANOMMUNE NANOSH NanoExpo(BY) NanoGesund HMGU NanoHouse	NEW DFG CarboSafe NANOMMUNE NANOSH NanoExpo(BY) NanoGesund NanoHouse
9	Stability of agglomerates under real technical conditions	Nanocare HMGU	Nanocare HMGU	Nanocare HMGU	Nanocare HMGU	HMGU	HMGU
10	Investigations into the real form of appearance (isolated nano-objects, agglomerates) in the body	HMGU NEW Nanosafe2 Nanocare	HMGU NEW Nanosafe2 Nanocare	HMGU NEW Nanosafe2 Nanocare	HMGU NEW Nanosafe2 Nanocare	Nanosafe2 HMGU	LENA HMGU
11	Decomposition mechanisms for agglomerates in bodily fluids	Nanocare INOS UniL	Nanocare INOS UniL	Nanocare INOS HMGU UniL	Nanocare INOS HMGU UniL	Nanocare HMGU UniL	HMGU UniL

2010		2011		2012		2013	
1st	2nd	1st	2nd	1st	2nd	1st	2nd
CarboSafe AnNa NanoLang KIT HMGU IANH InLiveTox NANOGENOTOX	CarboSafe AnNa NanoLang KIT HMGU NanoGEM IANH InLiveTox Carbon Black CarboTox NanoKon NanoMed NANOGENOTOX	CarboSafe AnNa NanoLang KIT HMGU NanoGEM IANH InLiveTox Carbon Black CarboTox NanoKon NanoMed NANOGENOTOX	CarboSafe AnNa NanoLang KIT HMGU NanoGEM IANH InLiveTox Carbon Black CarboTox NanoKon NanoMed NANOGENOTOX	CarboSafe NanoLang NanoGEM IANH InLiveTox Carbon Black CarboTox NanoKon NanoMed NANOGENOTOX	NanoGEM Carbon Black CarboTox NanoKon NanoMed NANOGENOTOX	NanoGEM Carbon Black CarboTox NanoKon NanoMed NANOGENOTOX	NanoGEM Carbon Black CarboTox NanoKon NanoMed
NANOMMUNE KIT HMGU NanoImpactNet InLiveTox VIGO NANOGENOTOX	NANOMMUNE KIT HMGU NanoImpactNet InLiveTox VIGO CarboTox NanoMed NANOGENOTOX	NANOMMUNE KIT HMGU NanoImpactNet InLiveTox VIGO CarboTox NanoMed NANOGENOTOX	NANOMMUNE KIT HMGU NanoImpactNet InLIveTox VIGO CarboTox NanoMed NANOGENOTOX	NanoImpactNet InLiveTox VIGO CarboTox NanoMed NANOGENOTOX	VIGO CarboTox NanoMed NANOGENOTOX	CarboTox NanoMed NANOGENOTOX	CarboTox NanoMed
CarboSafe AnNa NanoLang NanoTEST KIT HMGU AntiCarb POCO MAGISTER NANOGENOTOX	CarboSafe AnNa NanoLang NanoTEST KIT HMGU AntiCarb POCO MAGISTER CarboTox NanoKon NanoMed Ag-NP NANOGENOTOX	CarboSafe AnNa NanoLang NanoTEST KIT HMGU AntiCarb POCO MAGISTER CarboTox NanoKon NanoMed Ag-NP NANOGENOTOX	CarboSafe AnNa NanoLang NanoTEST KIT HMGU POCO MAGISTER CarboTox NanoKon NanoMed Ag-NP NANOGENOTOX	CarboSafe NanoLang POCO MAGISTER CarboTox NanoKon NanoMed Ag-NP NANOGENOTOX	CarboTox NanoKon NanoMed Ag-NP NANOGENOTOX	CarboTox NanoKon NanoMed NANOGENOTOX	CarboTox NanoKon NanoMed
KIT HMGU	KIT HMGU Carbon Black	KIT HMGU Carbon Black	KIT HMGU Carbon Black	Carbon Black	Carbon Black	Carbon Black	Carbon Black
CFN DFG NanoTEST KIT POCO MAGISTER NeuroNano InLiveTox	CFN DFG NanoTEST KIT POCO MAGISTER NeuroNano InLiveTox Carbon Black NanoKon NanoMed	CFN DFG NanoTEST KIT POCO MAGISTER NeuroNano InLiveTox Carbon Black NanoKon NanoMed	CFN DFG NanoTEST KIT POCO MAGISTER NeuroNano InLiveTox Carbon Black NanoKon NanoMed	CFN DFG POCO MAGISTER NeuroNano InLiveTox Carbon Black NanoKon NanoMed	CFN DFG Carbon Black NanoKon NanoMed	DFG Carbon Black NanoKon NanoMed	DFG Carbon Black NanoKon NanoMed
HMGU	HMGU Carbon Black	HMGU Carbon Black	HMGU Carbon Black	Carbon Black	Carbon Black	Carbon Black	Carbon Black
NEW DFG CarboSafe NANOMMUNE NanoExpo(BY) NanoGesund NanoHouse NanoExpo (BMBF)	NEW DFG CarboSafe NANOMMUNE NanoExpo(BY) NanoGesund NanoHouse NanoExpo (BMBF)	DFG CarboSafe NanoHouse NanoExpo (BMBF)	DFG CarboSafe NanoHouse NanoExpo (BMBF)	DFG CarboSafe NanoHouse NNanoExpo (BMBF)	DFG NanoHouse NanoExpo (BMBF)	DFG NanoExpo (BMBF)	DFG
HMGU	HMGU	HMGU	HMGU				
LENA HMGU	LENA HMGU NanoKon Ag-NP	LENA HMGU NanoKon Ag-NP	LENA HMGU NanoKon Ag-NP	LENA NanoKon Ag-NP	LENA NanoKon Ag-NP	NanoKon	NanoKon
HMGU UniL	HMGU UniL NanoMed	HMGU UniL NanoMed	HMGU UniL NanoMed	NanoMed	NanoMed	NanoMed	NanoMed

III.2.2 Overview of projects relating to research into the environmental safety of nanomaterials

Here again we present the results of national and international projects. According to the approach taken in chapter III.2.1, the main focus is once again on the national research projects on account of the fact that more data is available.

(Additional projects which relate to human toxicology aspects as well as environmental toxicology aspects can be found in the previous chapters.)

III.2.2.1 German research projects

Name	NanoFlow – mobility of synthetic nanoparticles in water-saturated subsoil and subsoil with variable water saturation
Funded by	BMBF
Duration	10/2009 – 09/2012
Task definition	The NanoFlow project conducts research into the effects of synthetic nano-objects on the environment. The focus here is on the behaviour and action of materials and products with integrated functional nanomaterials in the soil and groundwater. To do this, fundamental techniques and standard testing methods are developed for the determination of relevant action mechanisms and thresholds, with the aid of which the mobility of nanomaterials in the subsoil is to be studied. The results will be used as a basis from which laws can be derived for the mobility, stability and interactions between investigated materials and soil and water. The aim is the development of risk assessment models for the distribution of nano-objects in the soil and in groundwater reservoirs.
Results	Project has not been finished yet; no results published to date.
Further information	» http://webserver.lih.rwth-aachen.de/content/e35/e1049/ (in German language) » Neukum, C., Klumpp, E., Pütz, T., Klein, T., Azzam, R. (2010): NANOFLOW: Mobility of synthetic nanoparticles in the subsoil – project presented in: *Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften* 67 , 151

Name	AnNa (roadmap acronym) – Application of two of the most frequently used nanomaterials like titanium dioxide and silver in the fundamental test methods for characterisation of these substances
Funded by	German Federal Environment Agency
Duration	10/2009 – 11/2011
Task definition	Various nanomaterials are investigated in terms of their acute environmental toxicity on aquatic and terrestrial organisms according to standardised guidelines. The aim is not only to determine any harmful effects on the environment, but also to modify standardised test methods to the special properties of nanomaterials.
Results	Project has not been finished yet; no results published to date.

Name	NanoLang (roadmap acronym) – testing of selected nanomaterials in terms of their environmentally toxic long-term effects – modification of the test methods
Funded by	German Federal Environment Agency
Duration	10/2009 – 02/2012
Task definition	The project is looking at the long-term effects of nanomaterials on the environment. Here again, the applied standardised tests are to be adapted for nanomaterials.
Results	Project has not been finished yet; no results published to date.

Name	UmRiNa (roadmap acronym) – Environmental risks of nanomaterials: Investigation of the behaviour of selected nanomaterials under environmental conditions as a function of shape, size and surface characteristics
Funded by	German Federal Environment Agency
Duration	10/2009 – 10/2011
Task definition	In the project, standardised test methods (OECD guidelines) have been developed with regard to their suitability for nanomaterials, and modifications have been proposed where appropriate. The results obtained with these results will also deliver results for the behaviour and mobility of nanomaterials in the environment.
Results	Key results emerging from the project include: » Stable suspensions of the nanomaterials in the liquids required for the studies cannot be detected with a single set of dispersion instructions, » The wastewater treatment plant experiments showed a high nanomaterial retention capability; only a few percent of the added nanomaterials leaves the plant with the discharge; » The transport investigations carried out on nanomaterials in the ground indicated an accumulation in the upper ground layers in the column experiments. These and other results will be presented to an expert panel in the final report in October 2011 and then published.

Name	Nano-gTC (roadmap acronym) – Application of two of the most frequently used nanomaterials like TiO_2 and silver in the fundamental test methods for characterisation of these substances
Funded by	German Federal Environment Agency
Duration	10/2009 – 02/2012
Task definition	The project is looking at the application and possible need for adaptation of various OECD guidelines for the environmental toxicological investigation of nanomaterials. By way of example, the project uses various nanoscale titanium dioxide materials as well as a nanosilver material for this purpose. The different environmental areas water, soil and sediment are considered here.
Results	These will not become available until the final report has been written and a consultation has taken place with the German Federal Environment Agency.

Name	Fe-NANOSIT – Iron-based nanoparticles and nanocomposite structures for removal of pollutants from groundwater and waste water
Funded by	BMBF (German Federal Ministry of Education and Research)
Duration	05/2010 – 04/2013
Task definition	The aim of the Fe-NANOSIT project is to develop new cleaning technologies for waste water and groundwater purification which save energy and resources. Reactive nanomaterials are to be used for this purpose in order to make greater use of the high potential of nanotechnology for water purification applications. The main part of the work focuses on tailor-made, innovative and reactive nano-objects on the basis of iron/carbon composites as well as magnetic nanocatalysts. The regeneration of contaminated water resources with the aid of the new materials should be easy to handle, only cause low costs and only require short regeneration times. The commercial benefits of the new methods for groundwater and waste water purification should particularly be to the advantage of small and medium-sized companies. A comprehensive risk assessment and an environmental toxicology assessment for the new nanomaterials are to be included as part of the planned work.
Results	Project has not been finished yet; no results published to date.
Further information	http://www.nanoobjects.info/cms/lang/en/Projekte/Fe-NANOSIT

Name	NAPASAN – Use of nanoparticles for the cleanup and rehabilitation of contaminated groundwater
Funded by	BMBF (German Federal Ministry of Education and Research)
Duration	05/2010 – 04/2013
Task definition	The aim of the NAPASAN project is to further develop manufacturing processes for nano-objects (iron and nonferrous metals) taking into account the pollutants which are to be cleaned up as well as environmental aspects. The particles must be modified in such a way that transport is enabled in the ground zone and contact is established with the pollutants so that they are cleaned up. At the same time, a hazard assessment is to be performed for the application of these nano-objects, and proof is to be provided that they can be safely used to achieve success in the cleanup operation.
Results	Project has not been finished yet; no results published to date.
Further information	http://www.napasan.de

Name	NanoKiesel – Nanoscale silica sludge – technological developments for use in mineral construction materials in order to improve the material properties
Funded by	BMBF (German Federal Ministry of Education and Research)
Duration	05/2010 – 04/2012
Task definition	The aim of the project is to develop a recycling method for nanoscale silica sludge from industrial waste water treatment and the use of this nano-residue in construction materials in order to improve the material properties. This includes the development of processing technology and the investigation of various possible applications in the construction sector. The project includes the development of the machine and plant technology for processing the filter residue, with the aim of modifying it for subsequent use in various construction materials (tiles, concrete, plaster, mortar). The handling of silica waste during processing and further use will be assessed in terms of environmental toxicology, so that health and environmental safety requirements can be defined for the nanoscale residue.
Results	Project has not been finished yet; no results published to date.
Further information	http://www.nanoobjects.info/cms/lang/en/Projekte/NanoKiesel

Name	NanoSan – Nanotechnology cleanup and rehabilitation methods – *In situ* application of **iron** oxide nanoparticles to eliminate pollutants in pre-existing pollution
Funded by	BMBF (German Federal Ministry of Education and Research)
Duration	07/2010 – 06/2013
Task definition	During the course of the NanoSan project, a new method for biological *in situ* rehabilitation of petrol and tar oil groundwater damage is to be developed. In contaminated groundwater reservoirs, the potential for natural self-cleaning through microorganisms often cannot be exploited as there is no bioavailability of a rich abundance of iron(III) which can act as a stimulant for biodegradation. By using special **iron oxide** nanoparticles (which have been tested in terms of their environmental toxicological impact) directly at the centre of the contamination, bioavailability is to be improved and, in this way, an innovative *in situ* cleanup method devised. In terms of its basic approach, this new method will be significantly more efficient, more cost effective and better for the environment than previous conservative methods.
Results	Project has not been finished yet; no results published to date.
Further information	http://www.nanoobjects.info/cms/lang/en/Projekte/NanoSan

Name	MVV-Nano (roadmap acronym) – Mobility, behaviour and fate of nanomaterials in the different environmental media
Funded by	UBA (German Federal Environment Agency)
Duration	10/2010 – 08/2012
Task definition	Follow-on project from UmRiNa, the following key aspects: » Investigation of the influence of nano-object coatings on their behaviour in the environment, » Investigation of the stability of nanomaterial coatings under environmental conditions; development of coating analysis methods, » Consideration of the mobilisation of pollutants, the bonding of nutrients or the possible effects as catalysts during the transport of nanomaterials in soils.
Results	No published results are available yet.

Name	Nanorisk (German Federal Environment Agency) – Environmental risks posed by nanomaterials taking into account relevant exposure scenarios
Funded by	German Federal Environment Agency
Duration	11/2010 – 06/2013
Task definition	Within the project, several OECD guidelines are to be examined in terms of their suitability for assessing nanomaterials and refined if necessary. For a realistic risk assessment of nano-TiO_2, tests are carried out at various trophic levels (bacteria, water flea, fish, worm), at various effect levels (breathing, mobility, embryonic development, reproduction) and in various different environmental areas (activated sludge, water, soil). In addition, the combinatory effects of TiO_2 particles and an environmentally relevant chemical are to be investigated in terms of the impact on organisms.
Results	Project has not been finished yet; no results published to date.

III.2.2.2 European research projects

Name	NanoSafe Textiles
Funded by	TVS Textile Association of Switzerland and Empa (CH)
Duration	2007 – 2009
Task definition	The aim of this project was to take stock of the development trends of current and future applications for synthetic nano-objects in textiles and to highlight potential risks along the life cycle of textile applications.
Results	Translation of original German quotes from the final report (status: March 2010) relating to environment-related aspects of textiles modified with nano-objects[16]: "In terms of the environment, the picture which emerges is slightly different to the situation regarding health. Silicon dioxide, aluminium(hydr)oxides, montmorillonite, CNT and CB (carbon black) would appear to would appear to be safe, whereas silver and ZnO (zinc oxide) are more problematical, particularly since they become dissolved and the dissolved ion has a well-known toxic effect on organisms. Although the dissolution does not play a role in the case of TiO_2, it is however used in relatively high quantities and is the NP (nanoparticle) for which effects could be observed in some studies already at fairly low concentrations. However, these effects are still relatively weak, for example when compared to a number of pesticides approved for use in Switzerland. These appraisals will need to be re-adjusted depending on how many new nanoproducts are brought to market, and what their specific life cycles are."
Further information	http://www.swisstextiles.ch/news/allenews/archive-2010/?id=10756 (in German language)

Name	EXPO (roadmap acronym) – Exposure modelling for technical nanoparticles in the environment
Funded by	Empa (CH)
Duration	2008
Task definition	In the project entitled "Exposure modelling for technical nanoparticles in the environment" (EXPO), which was conducted at Empa in St. Gallen/Switzerland, the movements of nano-objects during the entire life cycle of nano projects is tracked, and an estimate is made as to when a release of nano-objects can occur, e.g. during production, in use or during disposal of a product. This life cycle modelling should not be confused with a life cycle analysis (LCA), which is the investigation and evaluation of the environmental impact of a product or service. The materials which were investigated were nanosilver, nano-TiO2 and carbon nanotubes (CNT).
Results	The new modelling approach of this work offers a quantitative starting point for the discussion about environmental effects of nano-objects. The results serve as a first basis on which environmental toxicology data can be compared and will help scientists to devise experiments which emulate natural conditions.
Further information	*Environ. Sci. Technol.*, 2008, 42 (12), pp 4447–4453

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Name	ENNSATOX – Engineered Nanoparticle Impact on Aquatic Environments: Structure, Activity and Toxicology
Funded by	EU
Duration	07/2009 – 06/2012
Task definition	The goal is the investigation and assignment of the structure and functionality of fully characterised synthetic nano-objects to their biological activity in aquatic environments, taking into account the influence of nano-objects on ecosystems from the start of their release until they are taken up by environmental organisms.
Results	Project has not been finished yet; no results published to date.
Further information	http://www.ennsatox.eu

On the next page, the projects listed here have been assigned to the questions raised in chapter III.1.2 and sorted chronologically. In cases where environmental toxicology or exposure investigations could also be assigned to the projects on human toxicology, these projects are also listed in the table.

III.2.2.3 Issues related to environmental safety aspects and to the release of nano-objects

Sequential number and description		2005		2006		2007		2008	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
	Development of methodologies for testing effects								
1	Development of globally harmonised methods for measurement of environmental impact and environmental toxicity (standardisation required)							CarboSafe	CarboSafe
2	Identification and preparation of reference nano-objects								
	Substance properties								
3	Determination of the agglomeration/ segregation of specific nano-objects (stability of the nano-object), generalisation of the results in order to develop a standard model for agglomeration/segregation			NanoTox	NanoTox	NanoTox	NanoTox	CarboSafe	CarboSafe
4	Aspects relating to the lifecycle (removal of dusts, recycling)					Nanosafe-Textiles	Nanosafe-Textiles	Expo CarboSafe Nanosafe-Textiles	CarboSafe Nanosafe-Textiles
	Behaviour and fate in the environment								
5	Determination of the mobility of persistent, technical nano-objects in surface waters, groundwater and soils (deposition, mobilisation, adsorption, desorption, kinetics, distribution, morphology) and the key parameters for definition of their mobility			NanoTox	NanoTox	NanoTox	NanoTox	CarboSafe	CarboSafe
6	Development of methodologies with the aid of which nano-objects in the environment (air, water, soil) can be identified and quantified at relevant (e.g. low) concentrations	NEW	NEW	NEW	NEW Nano-transport	NEW Nano-transport	NEW Nano-transport	NEW Nano-transport CarboSafe	NEW CarboSafe
7	Determination of the nano-object background exposure in the environment in order to be able to estimate the levels contributed from anthropogenic sources							CarboSafe	CarboSafe
	Effects on organisms								
8	Investigation of the uptake of persistent nano-objects by living organisms/ microorganisms (in vivo and in vitro). Compilation of the information relating to toxicokinetics, deposition and accumulation of persistent nano-objects and/or recording of the effect in environmental toxicology tests			INOS	INOS	INOS	INOS	INOS DFG CarboSafe	INOS DFG CarboSafe

Abbreviations used in the roadmap:

DFG: SPP 1313 of the German Research Community

NEW: Nanoparticle exposure in the workplace, IUTA, Duisburg

Otherwise, the explanations of the abbreviations can be found in the project descriptions.

2009		2010		2011		2012		2013	
1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
CarboSafe	UmRiNa AnNa NanoLang CarboSafe ENNSATOX	UmRiNa AnNa NanoLang CarboSafe NanoPharm NanoTrack UMSICHT ENNSATOX	UmRiNa AnNa NanoLang CarboSafe NanoPharm NanoSan NanoTrack UMSICHT CarboLifeCycle MVV-Nano ENNSATOX	UmRiNa AnNa NanoLang CarboSafe NanoPharm NanoSan NanoTrack UMSICHT CarboLifeCycle MVV-Nano ENNSATOX	UmRiNa AnNa NanoLang CarboSafe NanoPharm NanoSan NanoTrack UMSICHT CarboLifeCycle MVV-Nano ENNSATOX	CarboSafe NanoPharm NanoSan NanoTrack UMSICHT CarboLifeCycle MVV-Nano ENNSATOX	NanoPharm NanoSan NanoTrack UMSICHT CarboLifeCycle MVV-Nano	NanoPharm NanoSan NanoTrack UMSICHT CarboLifeCycle	CarboLifeCycle
		UMSICHT	UMSICHT	UMSICHT	UMSICHT	UMSICHT	UMSICHT	UMSICHT	
CarboSafe	CarboSafe	CarboSafe UMSICHT	CarboSafe UMSICHT CarboLifeCycle	CarboSafe UMSICHT CarboLifeCycle	CarboSafe UMSICHT CarboLifeCycle	CarboSafe UMSICHT CarboLifeCycle	UMSICHT CarboLifeCycle	UMSICHT CarboLifeCycle	CarboLifeCycle
CarboSafe Nanosafe- Textiles	UmRiNa CarboSafe Nanosafe- Textiles	UmRiNa CarboSafe NanoTrack UMSICHT NanoKiesel	UmRiNa CarboSafe NanoTrack UMSICHT NanoKiesel CarboLifeCycle MVV-Nano	UmRiNa CarboSafe NanoTrack UMSICHT NanoKiesel CarboLifeCycle MVV-Nano	UmRiNa CarboSafe NanoTrack UMSICHT NanoKiesel CarboLifeCycle MVV-Nano	CarboSafe NanoTrack UMSICHT NanoKiesel CarboLifeCycle MVV-Nano	NanoTrack UMSICHT CarboLifeCycle MVV-Nano	NanoTrack UMSICHT CarboLifeCycle	CarboLifeCycle
CarboSafe	CarboSafe UmRiNa NanoFlow	CarboSafe UmRiNa NanoFlow NAPASAN UMSICHT	CarboSafe UmRiNa NanoFlow NAPASAN UMSICHT CarboLifeCycle MVV-Nano	CarboSafe UmRiNa NanoFlow NAPASAN UMSICHT CarboLifeCycle MVV-Nano	CarboSafe UmRiNa NanoFlow NAPASAN UMSICHT CarboLifeCycle MVV-Nano	CarboSafe NanoFlow NAPASAN UMSICHT CarboLifeCycle MVV-Nano	NanoFlow NAPASAN UMSICHT CarboLifeCycle MVV-Nano	NAPASAN UMSICHT CarboLifeCycle	CarboLifeCycle
NEW CarboSafe	NEW CarboSafe UmRiNa NanoFlow ENNSATOX	NEW CarboSafe UmRiNa NanoFlow UMSICHT ENNSATOX	NEW CarboSafe UmRiNa NanoFlow UMSICHT CarboLifeCycle MVV-Nano ENNSATOX	CarboSafe UmRiNa NanoFlow UMSICHT CarboLifeCycle MVV-Nano ENNSATOX	CarboSafe UmRiNa NanoFlow UMSICHT CarboLifeCycle MVV-Nano ENNSATOX	CarboSafe NanoFlow UMSICHT CarboLifeCycle MVV-Nano ENNSATOX	NanoFlow UMSICHT CarboLifeCycle MVV-Nano	UMSICHT CarboLifeCycle	CarboLifeCycle
CarboSafe	CarboSafe	CarboSafe	CarboSafe CarboLifeCycle	CarboSafe CarboLifeCycle	CarboSafe CarboLifeCycle	CarboSafe CarboLifeCycle	CarboLifeCycle	CarboLifeCycle	CarboLifeCycle
DFG CarboSafe	AnNa NanoLang DFG Carbosafe Nano-gTC ENNSATOX	AnNa NanoLang DFG Carbosafe Fe-NANOSIT NanoPharm UMSICHT Nano-gTC ENNSATOX	AnNa NanoLang DFG Carbosafe Fe-NANOSIT NanoPharm UMSICHT CarboLifeCycle Nano-gTC Nanorisk (UBA) ENNSATOX	AnNa NanoLang DFG CarboSafe Fe-NANOSIT NanoPharm UMSICHT CarboLifeCycle Nano-gTC Nanorisk (UBA) ENNSATOX	AnNa NanoLang DFG CarboSafe Fe-NANOSIT NanoPharm UMSICHT CarboLifeCycle Nano-gTC Nanorisk (UBA) ENNSATOX	DFG CarboSafe Fe-NANOSIT NanoPharm UMSICHT CarboLifeCycle Nano-gTC Nanorisk (UBA) ENNSATOX	DFG Fe-NANOSIT NanoPharm UMSICHT CarboLifeCycle Nanorisk (UBA)	DFG Fe-NANOSIT NanoPharm UMSICHT CarboLifeCycle Nanorisk (UBA)	DFG CarboLifeCycle

III.2.3 Overview of the known studies on the release of nano-objects from composite materials and consumer goods

The studies listed here are divided into national and international studies. The level of detail in which the studies are presented depends on the available data.

At present, there are completed or on-going studies on the release of nano-objects from products in the following industries:

» Textiles,
» Paints and coatings,
» Composite materials.

Furthermore, the new approach developed in Switzerland for modelling the life cycle of nano-objects offers a good basis for discussions about the environmental effects of nano-objects.

III.2.3.1 German research projects

Textiles

Name	NAN-ON-TEX – Nano-based refining and functionalisation of textile surfaces for improved indoor climate and hygiene in motor vehicles
Funded by	BMBF (German Federal Ministry of Education and Research)
Duration	07/2005 – 06/2008
Task definition	Creation of a test set-up which allows mechanical tests to be performed on textiles.
Results	With the aid of the test set-up which was created, it was found out that particles with a diameter of less than one micrometre can be released under the effects of material stresses. The project is currently being continued on the improved test set-up at ITV Denkendorf.

Name	SiNaTex – Safety for manufacturers and consumers for nanotechnology in textiles
Funded by	Baden-Württemberg Stiftung gGmbH
Duration	2/2007 – 1/2009
Task definition	The main point of interest in the SiNaTex project was the development of testing technologies for detailed characterisation of emission and immission nano-objects which are released into the air from textiles and/or their coatings during use.
Results	As the outcome of the development, a test method is now available at ITV Denkendorf which can be used to detect and quantify airborne nano-objects ranging in size from 4 to 800 nm which can be released from fibre-based materials during processing or under use. The nature and intensity of the mechanical stress during the stress test can be varied according to the durability requirements placed on the textile. In the form of information about particle concentrations, particle size distribution, particle chemistry and particle shape, important basic information is available which can be used to draw conclusions about possible hazard potential. The investigations showed for example that the nanoparticle release potential of nanoparticle-based coatings can be reduced by correctly coordinating the textile additives with the process engineering.

Name	Nanosilver particles in textiles – risk for waste water purification plants?
Funded by	Internal research carried out by Freudenberg Forschungsdienste KG, Weinheim
Duration	2008
Task definition	Investigation into the release of silver from nanosilver-doped cleaning textiles
Results	Silver is released from the fabric into the washing water.

Name	UMSICHT – Assessment of the environmental dangers posed by silver nanomaterials: from chemical particles to technical products
Funded by	BMBF (German Federal Ministry of Education and Research)
Duration	05/2010 – 04/2013
Task definition	The topic for the UMSICHT project is to investigate and improve our understanding of the behaviour, fate and effect of silver nanoparticles in the environment. In addition, methods are to be developed or optimised for the production of silver nanoparticles with varying sizes, shapes and surface coatings and for their verification. Here, the properties of the particles play a key role in defining the behaviour and effects in the environment. In a further subproject, abraded particles are produced from real textile products, and the behaviour of these particles is investigated under preferably realistic conditions in a range of different scenarios.
Results	First publications are in progress.
Further information	http://www.nanoobjects.info/cms/lang/en/Projekte/umsicht

Paints and coatings

Name	Release of nanoparticles from paints in normal use
Funded by	German Paint and Printing Ink Association (*Verband der deutschen Lack- und Druckfarben-industrie, VdL*)
Duration	2008
Task definition	Investigation into the release of nanoparticles in day-to-day use of paints and lacquers for wooden flooring, furniture and buildings on wood and sheet metal
Results	This study commissioned by the Association of the German Paints Industry and performed at the Technical University of Dresden showed that the release of particles depends greatly on the substrate and the paint, but not primarily on the fact that nano-objects are incorporated in the paints. It was further also shown that the release of particles with a diameter below 100 nm is negligibly low (< 3 particles/cm^3). By comparison: In a normal living space there are around 5000 nano-objects in every cubic centimetre of air, while the levels along busy inner city roads can reach up to one million nanoscale dust particles.

Name	Release of nanoparticles from paints due to grinding
Funded by	German Paint and Printing Ink Association (*Verband der deutschen Lack- und Druckfarben-industrie, VdL*)
Duration	2009
Task definition	Continuation of the study "*Release of nanoparticles from paints in normal use*". In the second part of the study, coating films are worked with a handheld grinding tool, and the release of nano-objects from the coating films and the abraded particles produced as a result are investigated.
Results	It was shown that, again, there were no differences in terms of the numbers of released particles between coatings with and without nanoparticles. The added nano-objects still remain a fixed, integral part of the paint matrix in the abraded particles. From the results of the study, the Association of the German Paints Industry drew the conclusion that painted surfaces which contain nano-objects represent no risk for human health or the environment in everyday use.
Further information	Vorbau, M., Hillemann, L., Stintz, M. (2009), Method for the characterization of the abrasion induced nanoparticle release into air from surface coatings, *Aerosol Science* 40, 209 - 217.

Name	NanoTrack – Investigation of the life cycle of nanoparticles on the basis of $[^{45}Ti]TiO_2$ und $[^{105}Ag]Ag^0$
Funded by	BMBF (German Federal Ministry of Education and Research)
Duration	05/2010 – 04/2013
Task definition	The NanoTrack project investigates the behaviour of nanoparticular titanium oxide and nanoparticular silver from nanocomposite coatings under the effects of wear, release and transport; in addition, the project also focused on investigating the effects of the particles on ecosystems. The aim is the qualitative and quantitative recording of the relevant processes and boundary conditions under which the particles can make their way into the environment. In a second step, this shall then be used as the basis for deriving corresponding requirements for protection of the environment. In order to solve these complex questions in the sense of preventative protection of the environment, partners from industry and academia (materials science, geosciences and environmental toxicology) are working together in an interdisciplinary approach.
Results	Project has not been finished yet; no results published to date.

Composite materials

Name	TRACER – Toxicology and Health Risk Assessment of Carbon Nanomaterials
Funded by	BMBF (German Federal Ministry of Education and Research)
Duration	03/2006 – 02/2009
Task definition	During the course of the TRACER project, the release of CNTs from composite materials (polycarbonate, polyurethane, PEEK polymer) and from nonwoven materials was examined.
Results	Within the framework of the project, new findings on the biocompatibility/toxicity and release of carbon nanomaterials were assessed with regard to the relevance of the test methods and evaluated in terms of their workplace and health relevance. In addition, recommendations were compiled with regard to handling and workplace safety where possible. A release of CNT can only be expected if the CNT material is present in the form of a dusty powder, but not during subsequent activities during the course of which CNT materials are processed into composite materials. The evaluation of the published data and experimental findings in this project clearly shows that it is not possible to draw up general effect characteristics which are valid for all carbon nanomaterials on the basis of the existing database. In accordance with the BAuA/VCI guidelines, attempts should therefore be made to minimise exposure until specific limits have been defined for carbon nanomaterials. Based on the results of this project, the recommendations in the BAuA/VCI guidelines for protection of workers when handling nanomaterials are also applicable to carbon nanomaterials.
Further information	http://www.nanoobjects.info/cms/lang/en/Projekte/TRACER

Name	CarboSafe – Identification of the environmental toxicological potential of CNT on the basis of suitable measuring techniques
Funded by	BMBF (German Federal Ministry of Education and Research) (Project within the framework of the Innovation Alliance Carbon Nanotubes – Inno.CNT)
Duration	4/2008 – 3/2012
Task definition	Safety research for the handling of and for the life cycle of carbon nanotubes, including: » Investigation of the environmental toxicity of von CNTs » Separation of CNTs for process studies and for calibration of measuring instruments » Development of an evaluation routine for the determination of CNTs in airborne status » Release of CNTs from composites during grinding, drilling and during various recycling processes
Results	First results have been published and can be viewed at the following website: http://www.inno-cnt.de/de/backgrounder_carbosafe.php

Name	CarboLifeCycle
Funded by	BMBF (German Federal Ministry of Education and Research) (Project within the framework of the Innovation Alliance Carbon Nanotubes – Inno.CNT)
Duration	11/2010 – 10/2013
Task definition	CarboLifeCycle builds on the previous results of TRACER and CarboSafe. One new aspect is the degradation behaviour (wear/abrasion) of products containing CNTs. The measuring techniques for CNTs are to be refined in this project, and the potential release of CNTs from products containing CNTs as a result of environmental influences and the behaviour of CNTs in environmental media such as soils are to be investigated. The environmental toxicological investigations of CarboSafe are being widened in CarboLifeCycle in terms of potential long-term effects and effects at cellular level. Methods and measures are to be devised which help to ensure safety during processing and usage of CNTs and products containing CNTs.
Results	The project started at the end of 2010, and no results have been published yet.

III.2.3.2 European research projects

Textiles

Although this paper has a strong focus on European (and in particular German) research projects, one highly cited US study is also mentioned here:

Name	Release of nanoparticular silver from commercially available sock fabrics into water
Funded by	United States Environmental Protection Agency (EPA)
Duration	2008
Task definition	Investigation into the release of silver from nanosilver-doped socks
Results	The work carried out by Benn and Westerhoff at the Arizona State University clearly shows that up to 650 µg of silver is washed out into 500 ml of distilled water from commercially available socks containing up to 1360 µg silver / g sock. During the course of the study, silver particles ranging in size from 10 to 50 nm were found in the sock material and in the washing water. It was also shown that the washing water contained both colloidal and ionic silver. According to the authors, the rate at which the silver is washed out depends on the manufacturing process used for the textiles.
Further information	*Environ. Sci. Technol*. 2008, 42, 4133-4139

Name	Behaviour of silver-nanotextiles during washing
Funded by	Empa (CH)
Duration	2009
Task definition	Investigations into the release of nanomaterials from nine different textiles into the washing water. For the first time, real washing water was to be used here rather than distilled water, which makes the test conditions much more realistic.
Results	During this investigation carried out by Empa in St. Gallen, the textiles released between 1.3 and a maximum of 35 % of the total amount of silver. The release was not influenced by the use of bleaching agents. However, most silver particles were released during the first wash cycle; in addition, they mostly no-longer nanoscalar, but much larger instead, as a result of which the Swiss team came to the conclusion that it makes no difference whether conventional silver textiles or nanosilver textiles are washed. The burden on the environment from the nanosilver textile would actually be lower overall. As a result, this type of clothing item does not pose a special nano-endangerment.
Further information	» *Environ. Sci. Technol.*, 2009, 43 (21), pp 8113–8118 » *Science*, 2010, 330, 1054-1055

Paints and coatings

Name	Emission of technical TiO_2 nanoparticles from exterior facades into the aquatic environment
Funded by	EAWAG/Empa (CH)
Duration	2008
Task definition	As part of the project conducted by EAWAG and Empa from the Swiss town of Dübendorf, the emission of TiO_2 particles from exterior facade paints into the aquatic environment was to be tracked.
Results	The researchers found out that TiO_2 objects ranging in size from 20 to 300 nm were separated from both new and aged facade paint coatings as a result of natural weather conditions.
Further information	*Environmental Pollution* 156, 2, 2008, pp. 233-239; Rapid communication

Name	NanoHouse – Life cycle of nanoparticle-based house coatings
Funded by	EU
Duration	01/2010 – 06/2013
Task definition	» Focus on nanoparticles (TiO_2 and nanoAg) in paints and coatings for interior and exterior applications » Investigation into the ageing and release of these substances due to weather effects and mechanical destruction » Life cycle analysis » Potential effects for the environment, health and safety
Results	Project has not been finished yet; no results published to date.
Further information	http://www-nanohouse.cea.fr

IV. Further information

Many additional sources of further information have not been included in this paper, both because they would exceed its scope, but also because, in many cases, they offer no real additional information or do not match up closely enough in terms of the topics covered to have a significant influence on the content of this paper. In some cases, information was not included because barely anything more than a statement of intent was available in the publically accessible literature. However, in case anyone is interested and would like the opportunity to research matters further themselves, here is a list of the sources that were deliberately not investigated in more detail:

OECD database on research into the safety of manufactured nanomaterials
http://webnet.oecd.org/NanoMaterials

Cordis database for EU projects on this topic
http://cordis.europa.eu/nanotechnology/src/safety.htm

European NanoSafetyCluster
http://www.nanosafetycluster.eu

DaNa project website
www.nanoobjects.info

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