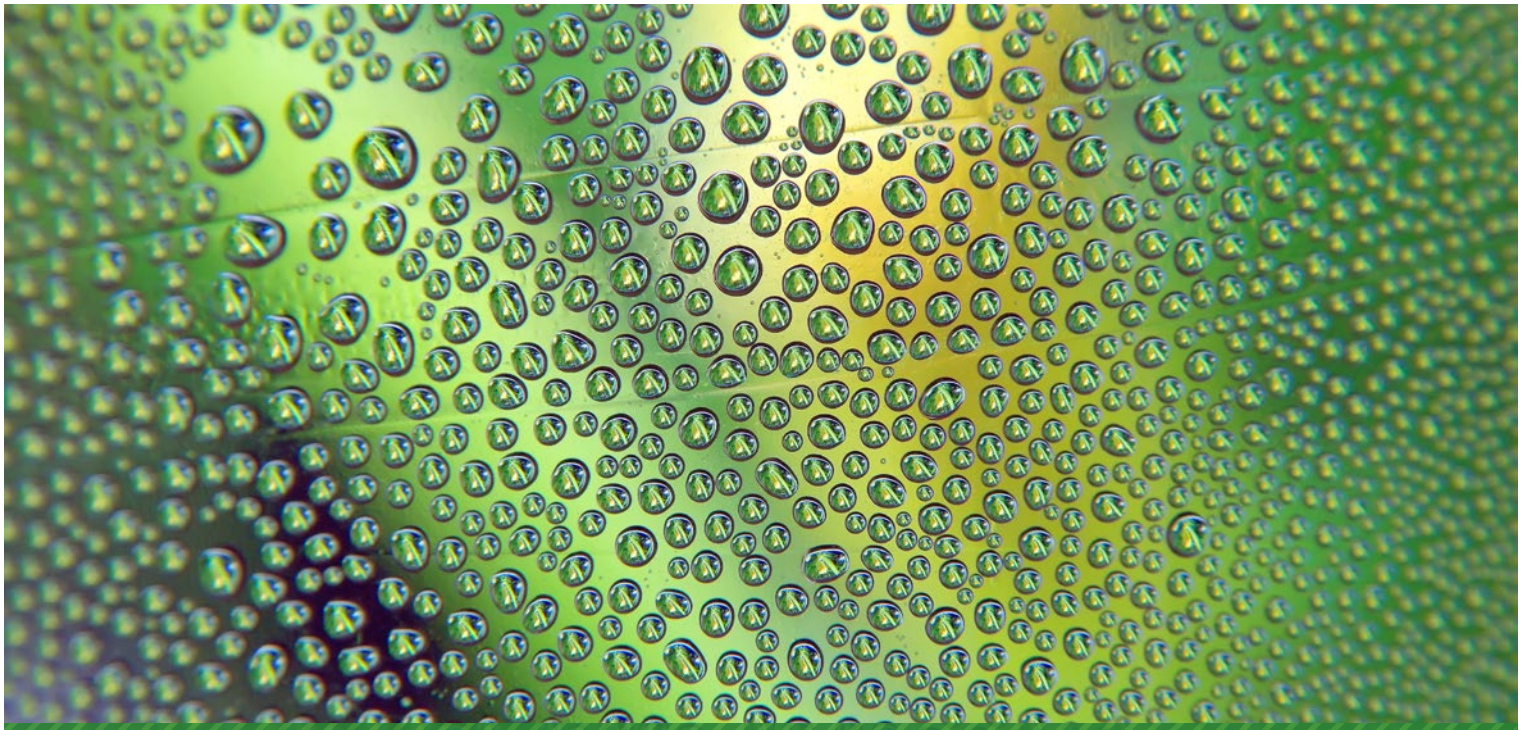


BACKGROUND // NOVEMBER 2020

Nanomaterials in the environment – Current state of knowledge and regulations on chemical safety

Recommendations of the German Environment Agency

German Environment Agency

Umwelt Bundesamt

Imprint

Publisher:
German Environment Agency
Section IV 2.2
PO Box 14 06
D-06813 Dessau-Roßlau
Tel: +49 340-2103-0
buergerservice@uba.de
www.umweltbundesamt.de

/umweltbundesamt.de
/umweltbundesamt
/umweltbundesamt
/umweltbundesamt

Authors:
Dr. Kathrin Schwirn, Section IV 2.2
Dr. Doris Völker, Section IV 2.2

In collaboration with:
Inga Andrä, Section IV 1.1
Susanne Bär, Section IV 1.3
Dr. Silvia Berkner, Section IV 2.2
Sina Egerer, Section IV 1.3
Cornelia Scholz, Section IV 1.2
Dr. Sascha Setzer, Section IV 1.2
Lars Tietjen, Section IV 2.3
Dr. Johanna Wurbs, Section III 1.4

Design:
le-tex publishing services GmbH

Publications as a pdf:
www.umweltbundesamt.de/publikationen

Photo credits:
Title: Shutterstock/DeSerg

As at: November 2020 (2nd edition)

ISSN 2363-829X

BACKGROUND // NOVEMBER 2020

Nanomaterials in the environment – Current state of knowledge and regulations on chemical safety

Recommendations of the German Environment Agency

Contents

1. Introduction

Nanotechnologies involve research and development, production and processing of structures and materials on a nanometre scale. Such nanomaterials[1] can have different or completely new properties and functions in comparison with conventional chemicals and materials. The most important fields of application for nanomaterials include electrical engineering, energy technology, chemistry and materials development, but also pharmaceuticals, coatings, construction materials, and textiles. By using the specific properties of nanomaterials, improved efficiencies or new functionalities can be achieved for a wide range of products and applications. Nanotechnology can offer various environmental opportunities, e. g. in the field of energy and resource efficiency, decontamination of wasteland sites, or water purification. But the dynamic development of nanomaterials and their applications means that the amounts produced are increasing. This can also result in increased burdens for humans and the environment when nanomaterials are released from products and applications.

In 2009, the German Environment Agency (UBA) published a background paper on the opportunities and risks of nanotechnology[2]. At that time, the potential benefits and impact of nanomaterials for humans and the environment still represented a relatively new field of research and some questions remain concerning the potential environmental benefits and the possible risks posed by nanomaterials. As a result of the findings from a range of scientific projects, research is no longer focused solely on the properties, behaviour and effects, but also addresses the adaptation of assessment tools for an appropriate regulation of nanomaterials.

Today, some, however not all substance legislations include specific provisions for nanomaterials yet. As a result, specific environmental risks cannot be described and assessed adequately and appropriate measures to minimize the risks cannot be taken. Therefore, the main aim of this paper is to outline the necessary further development of chemicals regulations for nanomaterials with regard to the environment from UBA's perspective. It is addressed particularly to players and decision-makers involved in discussions related to the adaptation of the various regulations on chemical safety. Firstly, the current state of knowledge about the environmental behaviour and the effects of nanomaterials is presented. The paper then considers general aspects of regulatory needs such as the definition of nanomaterials, their characterisation, and the assessment of related risks. It also describes the current consideration of nanomaterials in the existing active substance regulations as well as the specific requirements for adaptions. Finally, the activities of UBA are presented and the Agency's recommendations with regard to this topic.

2. Effects and behaviour in the environment – State of knowledge

In order to be able to make risk assessments, it is necessary not only to know the hazard potential of nanomaterials but also how about they are released and their fate and behaviour in the environment and the resulting environmental exposure.

In recent years, intensive research has provided new insights about the behaviour and effects of nanomaterials. Processes and mechanisms could also be identified that are important for the description of the behaviour and the impact of nanomaterials in the environment. These findings are summarised in the following subsection.

2.1. Effects in the environment

The fact that a substance is present as nanomaterial alone does not necessarily indicate a hazard potential. In addition to the chemical composition of a nanomaterial, its potentially harmful effect is also determined by properties such as its size, geometry, crystal structure, and surface properties (e. g. charge, surface chemistry)[3]. Furthermore, the ambient environmental parameters (e. g. pH-value, salinity, and content of natural organic substances) influence the properties of nanomaterials and can therefore affect their mobility, bioavailability, and the toxic effects in the environment[4]. Current investigations to determine the ecotoxic effects of nanomaterials focus primarily on nanomaterials with simple structures, some of which have already been on the market for many years but have not yet been considered specifically as nanomaterials in hazard investigations. Most of the findings relate to the effects on aquatic organisms. In recent years, increasing amounts of data have been generated also on the effects on soil organisms or sediment-dwelling organisms. Many of the nanomaterials investigated show only a moderate to low toxicity or no toxicity for environmental organisms after short-term exposure. A high acute toxicity for aquatic organisms can be observed for those nanomaterials that release ions with aquatic toxic effects (e. g. silver (Ag), zinc oxide (ZnO))[5]. Thereby, additional effects caused by the particles cannot be excluded[6]. Certain photo-catalytically active forms of titanium dioxide (TiO_2) show increased toxicity in laboratory tests under the influence of simulated sunlight[7]. In extended tests, some nanomaterials have been observed to lead to sub-lethal effects in fish, such as malformations in tissues and organs, damage to the gills, and developmental effects[8]. In addition, it has been found that aquatic organisms show changes in behaviour after short-term exposure to certain nanomaterials, e. g. changed feeding habits, increased flight behaviour, or their energy budget is influenced[9].

Since a large majority of nanomaterials on the market are inorganic, and are therefore not biologically degraded, it can be assumed that they will persist in the environment. In order to take the specialities of nanomaterials and their complex behaviour in the environment into account when determining ecotoxicological effects, it is not sufficient to investigate toxicity only after short-term exposure. Long-term effects on various invertebrate organisms have been investigated for a limited number of nanomaterials (mainly TiO_2, ZnO, Ag). It was found that exposing nematodes (“roundworms”) and daphnids (“water fleas”) to various nanomaterials (TiO_2, Ag, and gold (Au)) can lead to losses in the progeny, and over several generations to markedly increased mortality and limited reproduction[10]. There have as yet been no comprehensive and sufficient studies of the chronic effects on vertebrates such as fish that go beyond the larval stage.

Little information is available about the ecotoxic effects of nanomaterials on soil- and sediment-dwelling organisms, partly because of the methodological difficulties faced in such investigations. Some studies find no effects on soil- und sediment-dwelling invertebrate organisms, whereas other studies show that test organisms avoid soil contaminated with nanomaterials[11]. Further studies report changes in the reproduction rate (stimulation or suppression) after nanomaterials are introduced into the test soil[12]. However, these findings are not always clearly dose-dependent. Investigations with various plants show that they can take up and translocate nanomaterials. In some cases, an influence on germination

and growth was found[13]. Evidence has also been found for negative effects of TiO_2 nanomaterials on the biodiversity of soil microorganism communities[14].

Transformations and ageing of nanomaterials in the environment (e. g. sulphidation of metallic nanomaterials) can alter their ecotoxic effects. Studies with various environmental organisms show that effects can be increased or decreased[15]. However, since these studies were not carried out using the same test systems and organisms, it is difficult to compare the results.

In addition to the direct toxic effects, indirectly harmful effects on environmental organisms are also described for a number of nanomaterials. For example, it is known from laboratory tests that many nanomaterials can adhere to organisms and at sufficiently high concentrations they can block respiratory organs or the feeding apparatus[16]. On photosynthetically active organisms, e. g. algae, they can block out light, affecting metabolic processes. In addition, nanomaterials adsorb many of the available organic substances in the environment on their surface. This can also promote the uptake of harmful substances by organisms in the environment[17].

Despite the knowledge that has been gained about potentially harmful effects of nanomaterials on environmental organisms, assessing the environmental hazards of nanomaterials remains a challenge (see also section 3.1.3).

A comparison of the many studies on hazard assessment is made more difficult because the development of uniform specifications on application of the test item into the test systems and test performance is still under development.

On a case-by-case basis, it is necessary to check whether existing studies provide a suitable basis for an assessment of the environmental hazard. In many studies, the physical and chemical properties of the investigated nanomaterials are not described adequately. In other cases, there is no accompanying analysis and reference is only made to the nominal exposure concentration. This is questionable, because interactions of the particles between one another and with the test system can significantly change the effective exposure concentration.

2.2. Release into the environment

Nanomaterials find a very wide range of applications and with regards to their specific properties without limitation. Some nanomaterials, for example TiO_2, silicon dioxide (SiO_2) or carbon black, are produced in large tonnages and have already been used for decades, and indeed some nanomaterials were already used in ancient times[18]. These nanomaterials have found new applications as technology has developed. Other nanomaterials such as quantum dots or carbon nano tubes (CNTs) are relatively recent developments that have yet to establish themselves on the markets[19].

In order to be able to assess the environmental exposure to nanomaterials, it is important to know about the presence of nanomaterials in the various products and applications, and about their release over the life cycle (production, use, transport, recycling, and waste disposal). In many cases, qualitative and quantitative data about the uses and releases are insufficient to derive the potential environmental exposure.

The release of nanomaterials into the environment has been investigated exemplarily for the weathering and mechanical wear of various coatings, and for the washing of textiles[20]. Conceivable are also releases from sunscreen into recreational surface waters, or releases during the decontamination of wasteland sites, wastewater treatment, or the spray applications of pesticides[21].

Depending on the product and process in question, the released nanomaterials may be included in fragments of the product[22]. It has not yet been determined whether these fragments are further degraded in the environment to the extent that the included nanomaterials are finally released.

Experiments with model water treatment plants show that some 90 % of the nanomaterials investigated so far is retained in the sewage sludge, while less than 10 % finds its way into bodies of surface water[23]. The agricultural use of sewage sludge would therefore make the exposure of farmland likely. The fate of nanomaterials in soil has not yet been analysed sufficiently. But also irrespectively of the release of nanomaterials into the environment, the UBA is opposed to the agricultural use of sewage sludge in view of the known associated risks.

Initial investigations of the behaviour of nanomaterials (cerium dioxide (CeO_2), TiO_2) in waste incineration plants show that these are primarily included in solid residues such as slag and flue dust, while only negligible quantities are released with the cleaned flue gas[24]. The release of nanomaterials from landfill sites has hardly been investigated. The results of one study show the release of pigment TiO_2 in the leachate from building waste disposal sites. The possible release of nanomaterials into the environment by this route must therefore be taken into consideration[25].

In general, there are still qualitatively and quantitatively insufficient data on the release of nanomaterials into the environment for conclusions to be drawn about the entire life cycle. This is due in part to the manifold und high dispersive use of nanomaterials, but also to the methodological challenges involved and the lack of standardised methods.

2.3. Behaviour and persistence in the environment

The majority of the known nanomaterials on the market are inorganic, so that biological degradation usually plays only a subordinate role. Other processes such as (hetero-)agglomeration, sedimentation, adsorption of substances, adhesion to surfaces and transformation or dissolution determine the behaviour in the environment. These processes are affected by both the properties of the particles (e. g. size, geometry, surface properties) and the properties of the surrounding environmental medium (e. g. pH-value, salinity, concentrations of naturally occurring organic substances)[26]. Agglomerations lead to an attachment of individual particles by electrostatic and steric interactions. In the case of heteroagglomeration, nanomaterials agglomerate with particles occurring naturally in the environment. Depending on their density and state of agglomeration, nanomaterials settle out over time from the atmosphere or from aquatic systems to the ground or to the sediment.

Nanomaterials transform under environmental conditions by reduction or oxidation. They can adsorb other substances or may lose a synthetic coating due to mechanical, chemical or biological processes. These processes can reduce or enhance the mobility of nanomaterials and influence their bioavailability[27].

Investigations of the uptake, accumulation and persistence in environmental organisms have already been conducted for a limited number of nanomaterials. Most of these studies have been carried out with invertebrates such as water fleas and earthworms, but in some cases also with fish. The current findings indicate the potential of nanomaterials to accumulate in organisms, although generally at low levels[28]. In most studies, not only an uptake of nanomaterials but also good but often incomplete excretion could be demonstrated[29]. In experiments with fish und earthworms, despite good clearance of metal and metal-oxide nanomaterials an increase in the levels of the corresponding metallic elements in the peripheral organs was demonstrated[30]. Low accumulation with rapid uptake and release from the gut of fish was also demonstrated for multi-walled carbon nanotubes (MWCNTs). However, a few fragments of these nanomaterials reached the blood and muscle tissue[31]. Studies with earthworms show the possibility for the accumulation of metals and metal oxides after taking in corresponding nanomaterials[32]. Other studies have confirmed an uptake and accumulation of nanomaterials, for example in plants[33]. In various studies with mussels, the ingestion of nanomaterials by filter-feeding organisms could be demonstrated[34]. In reports on cell tests, possible uptake mechanisms in the cells of organisms have been described[35]. In particular, the incomplete clearance of nanomaterials by organisms at the beginning of the food chain is of critical importance. Several studies have shown that nanomaterials can be transported along simple food chains[36].

The data situation on the behaviour and persistence of nanomaterials in the environment and in environmental organisms has improved considerably in recent years. However, the usefulness of the data for an environmental assessment is limited because most of the studies are not based on consistent methodologies, so that comparisons are difficult. There is a need for standardised methods that take into account the specific processes for the description of the environmental behaviour.

3. Further development of legislation on chemical safety

Nanomaterials are in principle covered by the legislation and regulations on chemical substances. However, specific requirements which take into account the special features of nanomaterials for data collection and risk assessment are not available in all substance legislations. These deficits and possible options for adapting relevant regulations have been under discussion in various German and European bodies for a considerable time.

When adapting regulations to cover nanomaterials, findings about their behaviour and effects must be taken into account, as well as newly acquired knowledge about exposure and applications. This is important in order to ensure an appropriate assessment, to maintain the trust of civil society in nanotechnologies, and to provide legal certainty.

In this section, general requirements for the appropriate regulation of nanomaterials under the various laws and regulations on substances are first presented. The individual regulations on substances that are relevant for nanomaterials are then considered, in particular the EU Regulation for the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)[37], the EU Regulation on classification, labelling, and packaging of substances and mixtures[38] (CLP Regulation), the EU Regulation concerning the making available on the market and use of biocidal products[39] (Biocidal Products Regulation), the EU Regulation concerning the placing of plant protection products on the market[40], and the EU directives relating to medicinal products for human use as well as the EU regulation concerning veterinary medicinal products[41]. In Germany, the German Environment Agency is responsible for assessing the relevant environmental risks under these regulations. Furthermore, the needs for amending the criteria for awarding of the eco-label and the need for a European register of products containing nanomaterials are discussed.

3.1. Requirements for general regulatory amendments

3.1.1 Applying the definition for nanomaterials

A regulatory definition of nanomaterials is very important in order to ensure clarity about which materials are covered by a specific regulation. On

Concise EU Recommendation on the definition of a nanomaterial (2011/696/EU)

'Nanomaterial' means a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimension is in the size range 1 nm–100 nm.

In specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50 % may be replaced by a threshold between 1 and 50 %.

By derogation, fullerenes, graphene flakes and single wall carbon nanotubes with one or more external dimensions below 1 nm should be considered as nanomaterials.

For the application, 'particle', 'agglomerate' and 'aggregate' are defined as follows:
(a) 'particle' means a minute piece of matter with defined physical boundaries;
(b) 'agglomerate' means a collection of weakly bound particles or aggregates where the resulting external surface area is similar to the sum of the surface areas of the individual components;
(c) 'aggregate' means a particle comprising of strongly bound or fused particles.

Where technically feasible and requested in specific legislation, compliance with the definition may be determined on the basis of the specific surface area by volume. A material should be considered as falling under the definition where the specific surface area by volume of the material is greater than 60 m2/cm3. However, a material which, based on its number size distribution, is a nanomaterial should be considered as complying with the definition even if the material has a specific surface area lower than 60 m^2/cm^3.

18.10.2011, the European Commission issued a recommendation for a definition of nanomaterials[42] (see text box 1). The intention of the Commission was to review this recommendation until 2014 and if necessary to make amendments.

The German Environment Agency considers the proposed definition suitable, and welcomes the inclusion of natural and incidental nanomaterials. Any specification of the definition, e. g. to cover only manufactured nanomaterials, should be provided where necessary in the relevant regulations.

The applicability of the proposed definition was reviewed in 2014 and 2015 on behalf of the European Commission by the Joint Research Centre (JRC)[43]. Experience with the definition was collated and evaluated. In its final report, the JRC recommends retaining the scope of the definition to cover natural, incidental and manufactured nanomaterials with a size of 1–100 nm. In addition, eleven options are considered for making the definition clearer and thus simplifying its application. An important point in the opinion of UBA is the introduction of criteria to clarify the conditions under which a material is no longer covered by the definition, e. g. materials which contain only a negligible proportion of nanoscale impurities. On behalf of the European Commission, the JRC published two reports in 2019, which aim to support the implementation of the recommendation for a definition. The first report focuses on the concept and the used terms on the definition in a regulatory context[44]. The second report gives guidance how nanomaterials can be identified by measurements[45]. In addition to that there are currently several projects dealing with the development of OECD test guidelines and guidances which can support the identification of nanomaterials according to the recommendation on a definition[46].

Besides to the definition recommended by the European Commission, which has already been included into the annex IV of the REACH regulation (EU 1881/2018) as well as in the Biocidal Products Regulation (EU (No.) 528/2012), other definitions are used in a number of specific regulations which differ from the recommendation[47]. In order to achieve coherency and equality of treatment, the UBA declares oneself in favour for the use of a harmonised definition. This should follow the recommendation of the European Commission from October 2011.

To achieve a coherent regulation and subsequently equal treatment, UBA declares oneself in favour for a harmonised definition in the various legislations. This should follow the recommendation made by European Commission in October 2011. The development and harmonisation of methods to identify nanomaterials should be expedited.

3.1.2 Sufficient physical and chemical characterisation

The characteristics of a nanomaterial are influenced by its chemical composition and also by its size, geometry, crystal structure and surface properties (e. g. charges, surface chemistry, organic and inorganic coatings). Parameters can differ from the corresponding parameters for the non-nanoscale substance, or between various nanomaterials of the same chemical substance. In addition, some properties of nanomaterials (e. g. surface charge, solubility and agglomeration behaviour) depend on the properties of the surrounding environmental medium.

It is therefore necessary to fully characterise nanomaterials. This is an important precondition in order to be able to identify nanomaterials, to interpret and compare test results, but also in future to be able to predict possible behaviour and effects. This must be taken into account when formulating the requirements in the various regulations. Currently, various projects[48] are dealing with the development of OECD test guidelines and guidances which aim to allow a harmonised characterisation of nanomaterials[49].

Nanomaterials have to be fully characterised regarding their physical-chemical properties in order to be able to identify them as nanomaterials, and to be able to interpret and compare test results. This must be taken into account when formulating the requirements in the various regulations on chemical safety. The development of harmonised methods and guidance for physical-chemical characterisation need to be pursued rapidly.

3.1.3 Adaptation of risk assessment for nanomaterials

In order to be able to assess the potential environmental risks posed by nanomaterials, it is necessary to have appropriate estimates of the hazards and the environmental exposure.

Basically, the principles of environmental risk assessment for chemicals also apply for nanomaterials. These involve comparing the predicted environmental concentration with the concentration limit below which it is not expected to have any ecotoxicological effect. However, if the environmental risk of nanomaterials is to be assessed appropriately, there is a need for adaptations both with regard to the assessment of the concentrations in the environmental compartments (exposure assessment), as well as with regard to determining the concentrations that describe the ecotoxic effects on environmental organisms (hazard assessment).

Challenges for hazard assessment

The commonly used endpoints[50] in ecotoxicology such as the growth, mortality, and reproduction of various test organisms are in principle suitable for determining the ecotoxicity of nanomaterials. But adaptations are needed in order to take the special features of nanomaterials into account.

The ecotoxic effects of nanomaterials are influenced by their physical and chemical properties (chemical composition, shape, surface properties) and by the properties of the test medium (e. g. pH-value, salinity, concentrations of naturally occurring organic substances). For the correct interpretation and for the comparability of the test results it is therefore essential to have full details about the properties of both the nanomaterial in question and the test medium. However, many current available studies characterise nanomaterials and test media inadequately, severely limiting the usability of the results for hazard assessment. Ecotoxicological tests should also be accompanied by comprehensive analysis, demonstrating the concentration and the behaviour of the nanomaterial in the course of the test. The latter is particularly important in order to be able to determine the actual exposure concentration in the test system, which can differ considerably from the nominal concentration at the beginning of the test.

Currently there are no standardised procedures for introducing nanomaterials into the test systems, which means that the availability of the nanomaterials for the test organisms in the test systems can differ while the ecotoxic effects depend to a considerable extent on the procedure of the application used in the test. In order to increase the comparability and reproducibility of ecotoxicological studies it is therefore important to develop consistent methods for applying nanomaterials in the test (see section 3.1.4).

Assessments of the possible environmental hazard posed by nanomaterials are at present based mainly on studies involving short-term exposure. However, such studies are often inadequate for an assessment in view of the changed behaviour in comparison with the non-nanoscale form of a substance (including also different kinetic behaviour caused by low solubility in water or delayed dissolution), the higher persistence and longer bioavailability. Findings are needed about long-term effects in the environment and effects after ageing of the nanomaterials. In order to be able to make reliable statements about the environmental hazard that can be presented by nanomaterials, valid long-term studies are preferable to acute studies.

On the basis of the behaviour of nanomaterials, it can be assumed that soil and sediments are key target compartments in which nanomaterials accumulate in the longer term. Therefore, it is important to consider the ecotoxic effects on soil organisms and sediment-dwelling organisms at an early stage. However, depending on the legislation in question, these organisms are only considered in the hazard assessment under specific conditions. In the opinion of the UBA, more attention should be paid to the effects on soil and sediment-dwelling organisms in hazard assessments for nanomaterials.

The evaluation of the effects on selected test organisms is normally based on the principle that a higher exposure concentration will have greater effects (dose-effect relationship). However, nanomaterials may show increased agglomeration and sedimentation at high concentrations caused by higher particle interaction. In contrast, an improved distribution at lower concentrations can mean that the nanomaterial is more available to the test organisms, so that low-dose effects seem possible in the test. If no effects are observed in the hazard assessment at high

exposure concentrations, this does not exclude the possibility of effects on the test organism at lower exposure concentrations. This must be taken into account in hazard assessments, e. g. by conducting more tests over a wider range of exposure concentrations, or by more detailed analysis of the available concentration of the nanomaterials in the test system.

In the frame of a standardised test, only the outcome of ecotoxic effects is taken into account (e. g. mortality), but not the underlying molecular mechanism. If nanomaterials release ions that are known to have ecotoxic effects, it is an open question whether the toxicity is due solely to the release of toxic ions or whether the nanoscale character of the metal also contributes to the ecotoxicity. In order to be able to evaluate in particular the long-term behaviour and effects of ion-releasing nanomaterials, it is necessary in the course of the environmental hazard assessment to determine the intensity of the ion release over time, and where appropriate in which period the nanomaterial dissolves, respectively. In this context, it is essential to develop criteria for determining when a nanomaterial can be considered to be fully dissolved. In turn, it may then be possible to determine if and under which conditions one could abstain from a nanomaterial specific assessment.

For photo-catalytically active forms of nanomaterials, it is important to consider natural light conditions rather than artificial lighting when determining ecotoxic effects (in particular with aquatic organisms)[51]. Furthermore, by attachment on the surface of the test organisms, or blocking respiratory organs or the feeding apparatus, nanomaterials can affect the feeding habits and mobility of the organisms, or processes such as moulting, which in turn may impair their vitality and influence the outcome of the ecotoxicological test. The instruments to derive the environmental hazards focus on direct toxic effects of substances. In the opinion of the UBA, the hazard assessment of nanomaterials should also take into consideration the potentially increased toxicity under sunlight as well as the above-mentioned indirectly harmful effects.

The effect concentration of conventional chemicals is described in terms of mass to volume or weight of the test medium (water, soil, sediment). However, for nanomaterials the toxicity is also determined with reference to the particle size or the total external surface area. To describe the environmental hazard posed by nanomaterials it is necessary to determine whether the reference to particle surface area and numbers is more relevant than the reference to the mass.

In the view of UBA, the obligations for information within the various provisions should prefer long term studies rather than acute studies. Also, effects on soil and sediment organisms need greater considerations. For the hazard assessment, beside the chemical toxicity also effects caused e. g. by mechanical influences, photo-activity or additional particle toxicity need to be included. For the ecotoxicological investigation of nanomaterials both the investigated nanomaterial and the used test medium are to be characterised sufficiently and accompanied with appropriate analytics.

Challenges of exposure assessment

Whereas considerable amounts of data have been generated in recent years for assessing the effects of nanomaterials on environmental organisms, the data situation is much more limited with regard to production quantities, fields of application and sources of release, all of which are important for assessing potential environmental exposure. In principal, applicable methods and techniques are available to determine the presence of nanomaterials in environmental compartments, however, sample collection, extraction and analysis need to be standardised[52].

The established models usually used to assess environmental exposure focus on production and use data and release data in combination with information about the behaviour and fate of substances in order to derive concentrations in the various environmental compartments. However, many of the principles and methods on which these models are based are not appropriate for nanomaterials. Existing models on exposure assessment assume thermodynamic processes in which the distribution between the various environmental compartments reaches a concentration equilibrium. But this is not the case for nanomaterials[53]. The behaviour and persistence of nanomaterials in the environment is subjected mainly to kinetic processes such as agglomeration

and sedimentation. Besides, the dissolution rate is of importance. A significant proportion of nanomaterials may also adhere to the surfaces of solids present in the environmental compartments. Biodegradation, an important parameter for determining the environmental exposure of many substances, is not really relevant for many nanomaterials, which are mainly inorganic. More important factors for reliable exposure assessment are abiotic changes, e. g. by chemical transformation, by loss of surface coating, or by adhesion to other substances. These factors influence the behaviour and the effect of nanomaterials in the environment. However, such processes, which are characteristic for the behaviour and persistence of nanomaterials in the environment, find little or no consideration in the existing exposure models and regulatory information requirements. These must therefore be adapted in order to improve the description and assessment of the qualitative and quantitative distribution and the fate of nanomaterials in the environment.

In the opinion of UBA, for the exposure assessment of nanomaterials, specific obligations on adapted information requirements need to be made within the various regulations. Beside agglomeration behaviour and dissolution rate, important parameters are abiotic changes, e. g. due to chemical transformation, loss of surface coating or binding of other substances. These parameters have to be incorporated into exposure models.

3.1.4 Nano-specific procedures for harmonised testing of environmental fate and effects

For the reproducible and comparable testing of chemicals, there are a series of standardised, internationally harmonised, and accepted models, test guidelines and guidance documents[54]. These were developed primarily for more or less water soluble organic chemicals.

In 2007, in the framework of the OECD chemicals programme activity "OECD Working Party on Manufactured Nanomaterials", OECD launched the so-called Sponsorship Programme (2009–2014) in which 14 representative nanomaterials were to be tested[55]. The remit was to examine whether the existing OECD test guidelines for chemicals could also be applied for nanomaterials or whether amendment is required. It was concluded that the existing test guidelines are generally applicable, but that there are requirements for adaptations and additions. At an OECD meeting of experts on the environmental behaviour and ecotoxicology of nanomaterials, the suitability of selected OECD test guidelines for the testing of nanomaterials was discussed and recommendations for adaptions were made[56]. The identified need for adapting the OECD test guidelines arises primarily from the difference between the behaviour of soluble organic chemicals and of nanomaterials in the environment and in the corresponding test systems. This means it is not possible to obtain reliable data for nanomaterials with these test guidelines in their present form.

Next to the development of new test guidelines especially for environmental fate of nanomaterials, there is a need for additional guidance documents to support the application of existing test guidelines for the testing of nanomaterials. This applies in particular for the application of nanomaterials into the test systems, for accompanying analysis and the interpretation and documentation of results. The existing instructions allow leeway in carrying out the tests that are justified for conventional chemicals. However, when they are applied for nanomaterials, this makes it difficult to obtain reliable, comparable results[57]. Currently, several OECD test guidelines and guidances for nanomaterials are under development or already finalised, respectively[58].

For the appropriate risk assessment of nanomaterials also the specific characterisation of the properties of the investigated nanomaterial, e. g. particle size and distribution, surface chemistry and surface charge is essential. Therefore, the development of specific OECD test guidelines to characterise the physical and chemical properties of nanomaterials are of central importance. In addition to the development of the OECD guidance documents and test guidelines for determining the environmental behaviour and

environmental effects of nanomaterials, the development of test guidelines on determining the physical and chemical properties is currently promoted at OECD level. Information on current activities as well as finalised test guidelines and guidances on nanomaterials can be found at the webpage of the OECD test guideline program[59].

In the view of UBA, amendment and development of nanomaterial specific OECD test guidelines and guidance documents are important components for the appropriate assessment of the environmental risks of nanomaterials. UBA is leading various activities for the development of OECD documents with relevance to environmental assessment.

3.1.5 Developing nano-specific substance group and analogue approaches

Approaches to meet data requirements in deviation from performing standard test requirements are already established for chemical substances. One of these is the grouping and read-across/analogue approach. The aim is firstly to predict the physical-chemical, (eco)toxic, and behavioural properties of chemical substances based on structural similarities. If sufficient evidence is available it should then be possible to transfer available data on the hazards of one chemical substance to another one.

This approach is intended to reduce the amount of testing necessary to determine the behaviour and effects of all individual members of a group. In addition, the number of experiments with animals should be reduced. OECD[60] and ECHA[61] published guidance on the general use of substance grouping and read-across approaches. In 2017, ECHA published an annex to their guidance (with revision in 2019) which gives advice on how to approach grouping and read-across concepts for nanomaterials[62]. For this, parameters or combinations of parameters need to be identified which are important for distinguishing or comparing different nanoforms[63], e. g. chemical identity, intrinsic particle properties such as size and morphology, or extrinsic particle properties such as dissolution or agglomeration behaviour[64]. The reactivity of the nanoforms can also be an important parameter for grouping nanomaterials. Both the ECHA and the OECD have identified the development of grouping and read-across concepts for nanomaterials as a key field for the assessment and regulation of nanomaterials. The opportunities and limitations of these concepts are not conclusively investigated yet. This conclusion in particular concerns the development of concepts for grouping and read-across for nanoforms with regard to similar ecotoxic effects[65].

Given the numerous manufactured nanomaterials already on the market and expected in future, the effort for the individual investigation and assessment would be enormous. Therefore, it is necessary to develop approaches that allow an adequate hazard assessment of nanomaterials while avoiding individual testing of a large number of the different forms.

3.2. Regulatory deficits and the need for adaptations

3.2.1 Chemicals

The manufacture, import and use of chemical substances are regulated in the European Chemicals Regulation REACH (EC (No.) 1907/2006). According to that a registrant is obliged to assess the hazards of the substance and the risks associated with it, in order to be able to provide sufficient protection for humans and the environment. Among other things, data must be presented to ECHA on (eco-)toxicity and the uses, with an estimate of the extent to which humans and the environment could be exposed to these substances over the entire life cycle. The information requirements for the substance are specific to the tonnage bands, depending on the quantity manufactured or imported annually (1, 10, 100, or 1000 tonnes per annum and manufacturer). There is a broad consensus that REACH, with its approaches, tools, and methods (tests for hazard assessment, risk assessment and risk management measures) also provides a suitable framework for the secure handling of nanomaterials. However, adaptations are needed to take the special features of nanomaterials into account. Discussions on amending REACH have been going on for many years.

Clear specifications are required for nanomaterials regarding the information requirements, and transparent presentation in the registration dossier. REACH did not provide details concerning information requirements and the chemical safety report for nanoscale forms of substances. In the interests of legal clarity, equality of treatment and compliance with the precautionary principle, it was necessary for the demands on nanomaterials to be stated clearly in REACH. This also considerably reduced the challenges presented by applying REACH instruments for nanomaterials, such as dossier evaluation, substance evaluation or the preparation of safety data sheets.

Proposals for regulating nanomaterials were already published by the environmental groups Client Earth, CIEL and BUND in November 2012[66] and by the Swedish Chemicals Agency (KemI) in April 2013[67]. An approach for the special regulation of nanomaterials under REACH was developed by UBA in cooperation with the German Federal Institute for Occupational Safety and Health (BAuA) and the Federal Institute for Risk Assessment (BfR). This was presented to the European Commission and other EU bodies in May 2012 and published in January 2013[68].

In October 2017, upon long informal discussions, the European Commission finally presented its first official proposal on how to amend the REACH annexes to nanomaterials. The final version was published in the Official Journal of the European Union in December 2018. The specific requirements for nanoforms of registered substances as described in the amended annexes are applicable as from 1 January 2020[69,70]. With these amendments, transparency is created, if and which nanoforms of a substance are addressed by a registration. The recommendation on a definition of nanomaterials as well as a definition of nanoforms of a substance were included. For nanomaterials a comprehensive physical-chemical characterisation becomes necessary. In addition, information requirements specific for different endpoints on human health and environment were created. These concern inter alia inhalation as new standard uptake route for toxicological testing and ecotoxicological long term tests instead of short term tests. Furthermore, information on dispersion stability and dissolution rate of nanomaterials in relevant environmental media need to be submitted. To support registration and assessment of nanomaterials, ECHA published nanospecific annexes to its guidance[71].

In June 2020, amendments of annex II of the REACH regulation were published in the Official Journal of the European Union[72], which allow transparency on nanoforms within safety data sheets. Applicable as from 1 January 2021, the safety data sheet shall mention whether and which different nanoforms it covers and link the relevant safety information to each of those nanoforms. The particle characteristics that specifiy the nanoform have to be indicated. In order to comply with these new obligations, a transition period until 31 December 2022 was established.

Already before the REACH annexes were amended to nanomaterials, there were indications or evidence that some of the registered substances are nanomaterials or that a substance is also marketed as a nanomaterial. A substance evaluation of nanomaterials under REACH had been carried out by the Netherlands for SiO_2 and silver. In 2018, France started the evaluation of TiO_2, which was initially intended for 2014.

BfR, BAuA and UBA jointly work on substance evaluations for nanocale ZnO, multi-walled carbon nanotubes (MWCNTs), and nanoscale CeO_2[73].

For nanomaterials, clear obligations regarding information requirements and transparency within the registration dossiers are required. In the sense of legal clarity, equal treatment and for the fulfillment of the precautionary principle, it was needed that these obligations are clearly specified. In the framework of REACH, specific, legally binding information requirements for nanoforms of substances exist since 01.01.2020.

3.2.2 The classification, labelling and packaging of chemical substances and mixtures

The classification, labelling, and packaging of substances and mixtures are not subject of REACH but to the CLP Regulation which came into force on 20 January 2009 ((EC) No. 1272/2008). The CLP Regulation aligns the European Union system of classification, labelling and packaging of chemical substances and mixtures to the UN's Globally Harmonised System (GHS). The goals of the GHS are the simplification of world trade and at the same time the protection of human health and the environment by the introduction of a consistent global system for hazard identification and hazard communication. With only a few exceptions, all substances and mixtures are covered by the CLP Regulation. The classification is hazard-related and is made on the basis of specified criteria and limit values in various hazard classes and hazard categories. On this basis, appropriate labelling is derived with hazard and safety precautionary statements. The classification criteria of the GHS or CLP Regulation are intended to be applied for all chemicals and are to be applied to the actual form in which a substance is brought onto the market. This means that manufacturers, importers and subsequent users must take into account whether the chemical substance in question is a nanomaterial and base their decision for the classification on form-specific data.

It is necessary to check whether the existing GHS classification criteria are applicable for nanomaterials. To this end, a working group has been set up at the UN level which reviewed the applicability of the current classification criteria using available information on nanoscale TiO_2 and CNTs as examples. With regard to criteria relevant for environmental classification, the working group concluded that additional sets of data are needed to be able to draw final conclusion on their applicability for classification of nanomaterials. One the one hand this concerns the quality of data on aquatic toxicity. On the other hand, this also relates to the minor relevance of data on biotic degradation for classification of chronic toxicity of nanomaterials. It is expected that data on transformation will be more significant for many nanomaterials. The question arises, whether experiences from classification of metals and metal compounds may help to improve classification of nanomaterials. Furthermore, a discussion is needed on alternative classification criteria for bioaccumulation.

A distinction is made between self-classification by the person who is responsible for placing the chemical substance on the market and the legally-binding harmonised classification by the competent authorities. Since the form of a substance has to be taken into account according to CLP, data should be used that have taken into consideration the specific requirements for the investigation of nanomaterials.

For the classification according to CLP the form of the substance has to be considered. In the view of UBA, the classification of a nanoform of a substance should base on data which was collected taking into account the specific demands for the testing of nanomaterials.

3.2.3 Biocidal products and plant protection products

Plant protection products and biocidal products represent a probably environmentally relevant open application for nanomaterials. Indications for the use of nanomaterials in biocidal products and plant protection products provides for instance the French register of nanomaterials. Here, three substances (for biocidal products) and twelve substances (for plant protection products), respectively, are listed[74]. In its nano-inventory, produced on the basis of a literature search, the European Food Safety Authority (EFSA) assumes the use of up to 39 substances in nanoscale form in plant protection products and 12 in biocidal products in the areas of agriculture, food, or feed[75]. It is to be expected that the use of nanomaterials in biocidal products and plant protection products will become increasingly important[76].

Nanomaterials are used with the aim of reducing the amounts of active substances required and increasing the overall efficiency of their application. Used as co-formulants or directly as active substances, the greater specific surface area or increased adsorption potential of nanomaterials could help to reduce the loss of active substances by processes such as run off, evaporation or leaching into groundwater. Specifically formed external surfaces of nanomaterials could protect active substances against unwanted degradation by microorganisms or by light. The efficiency of a biocidal product or plant protection product can also be increased by the controlled release of the active

substances in capsule or targeted delivery systems made up of nanoscale components. Formulations are conceivable including nanomaterials that ensure better solubility and distribution of active substances, replacing or supplementing conventional co-formulants. The increased reactivity of nanoscale active substances could lead to a reduction in the necessary quantities of active substances, co-formulants, or overall formulations.

Because of the expected increase of nanomaterial's application in plant protection products and biocidal products a future increase in the release of nanomaterials or nano-formulated active substances into the environment must be expected. To identify a potential risk as a result of the application of nanomaterials and to protect the environment against negative consequences, it is necessary in the course of approval of active substances and authorisations of biocidal products and plant protection products to take the properties of nanomaterials into account.

Biocidal products

Under the Regulation of the European Parliament and of the Council concerning the making available on the market and use of biocidal products ((EU) 528/2012)[77] in the European Union, manufacturers or importers must successfully go through a two-stage authorisation process. In a first step, the biocidal active substance is evaluated in an EU procedure. After an active substance has been given EU-wide approval, in a second step, the product authorisation procedure, a decision is taken about the authorisation of a specific biocidal product at the national levels. This is mostly performed with participation of other member states (procedure of mutual recognition or union authorisation). In the Biocidal Products Regulation, nanomaterials in accordance with the definition proposed by the European Commission are expressly mentioned. They must be noted in the product's labelling and their health and environmental risks must be considered separately. This means, that the notification, assessment and approval of the nanoscale form of an active substance must be carried out separately from any potentially existing non-nanoscale form. Under the Biocidal Products Regulation, nanoscale active substances had to be registered as such by the end of October 2015. Currently, two nanoscale active substances are approved under the EU Review Programme (synthetic amorphous SiO_2 and SiO_2 "as a nanomaterial formed by aggregates and agglomerates" for insecticides). Active substances are currently being evaluated for two other nanomaterials (nanoscale silver as disinfectant and material preservative, and Ag adsorbed on SiO_2 as material preservative). The application documents for approval of an active substance had to be submitted to ECHA by December 2017. The Review Programme for active substances ends in 2024, i. e. all active substances for which applications have been submitted, including nanoscale active substances, must have been evaluated by then. In the interim, transitional rules apply for all registered active substances under which the nanoform of these active substances may still be used. Furthermore, nanoscale active substances can be submitted for authorisation as new substance. However, corresponding products including these active substances are allowed to be made available on the market only after agreement on the product authorisation, which follows the active substance approval.

Although nanomaterials are regulated under the Biocidal Products Regulation in principle, at present it does not include specific data requirements regarding physical and chemical properties or specifications for risk assessment.

For these reasons, a specific further development of the basis of assessment is needed in the opinion of the UBA. In particular, binding requirements are needed concerning physical and chemical characterisation and specific information about the behaviour and effects of the nanoscale active substances. Guidance must be prepared by ECHA with expert support from the Member States in order to provide assistance for applicants. If the authorities are to be able to properly examine the application documentation it is essential that all evaluating bodies have access to the data on the characterisation of the nanoscale active substances. Only then is it possible to identify the nanoscale active substance as such and to determine whether an appropriate investigation of the behaviour and effects is carried out taking the specific properties of the nanomaterial into account, in order to provide a sound basis for an assessment.

The use of nanomaterials as co-formulant in biocidal products is possible (e. g. pigments) and represents a further potential route of entry of nanomaterials into the environment. In case nanoscale co-formulants are part of a formulation of a biocidal product, these co-formulants have to undergo an environmental risk assessment. Thus, a biocidal product can only be authorised if no unacceptable environmental risks are associated with the nanoscale co-formulants.

There is a demand for binding specifications for the physical-chemical characterisation and specific information requirements regarding behaviour and effects of nanoscale active substances in the frame of the assessment of biocidal products. Also related guidance needs to be developed.

Plant protection products

The approval and authorisation of plant protection products and their active substances, respectively, is carried out in Germany on the basis of the Regulation of the European Parliament and Council concerning the placing of plant protection products on the market (Regulation (EC) No. 1107/2009) and the German Act on plant protection (PflSchG). The Europe-wide approval of an active substance is valid for ten years for the first approval, and 15 years for renewed approval. After that a new application must be made. This provides an occasion to examine whether approval is still justified in the light of advances in science and technology. The evaluation and authorisation of the actual plant protection product is carried out in a second step in the relevant Member States.

There are currently no specific provisions concerning nanoscale active substances and other nanoscale components, respectively, in plant protection products. It is possible that preparations containing nanomaterials are evaluated in the course of EU active substance approval or product authorisation.

As is the case for biocidal products, it is very likely that nanomaterials are already used in plant protection product formulations as synergists, safeners, and other co-formulants. The nano-inventory commissioned by the EFSA includes a number of products using nano-emulsions or encapsulation techniques with nanomaterials that are already on the market or will soon be marketable[78].

Since May 2015, within the application for authorisation of a plant protection product in Germany, the applicant has to report if nanomaterials according to the EU definition are deliberately introduced to achieve a specific effect. This requirement includes information on the substances, their content and function within the formulation. Other nanoscale components, i. e. those without intended effect are not obligatory to disclose. A survey conducted by the German Federal Office of Consumer Protection and Food Safety (BVL) addressing owners of authorisation and approval in February 2015 showed that some co-formulants can be considered as nanomaterials, without having an intended effect within the formulations, e. g. silica dioxide or colouring pigments[79].

In the opinion of the UBA it is necessary to establish technical and legal bases which ensure that plant protection products containing nanomaterials can be adequately assessed concerning their environmental risk. As discussed with respect to REACH and the Biocidal Products Regulation, the regulation of nanomaterials or nanoscale active substances in plant protection products also requires the introduction of a definition, as well as provisions for the physical and chemical characterisation and specific information requirements for risk assessment. In view of the potentially different kinetics and bioavailability in comparison with conventional active substances or formulations, nanoscale active substances or formulations with nanoscale components should be subjected to a separate assessment of hazards and exposure in the course of the approval and authorisation procedures. Corresponding guidance must be developed and harmonised which explain what has to be taken into consideration for the environmental risk assessment of a nanoscale active substance or a plant protection product with nanoscale components in the formulation. In 2018, EFSA published the first part of its Guidance on risk assessment of the application of nanoscience and nanotechnology in the food and feed chain which also covers plant protection products[80]. This first part is focusing on human and animal health related guidance only. A second guidance focusing on environmental risk assessment

is currently under development which will provide nanospecific assistance for the environmental risk assessment of inter alia plant protection products.

In the opinion of UBA, it is necessary to establish technical and legal bases which ensure that plant protection products containing nanomaterials can be adequately assessed concerning their environmental risk. In addition, related guidance needs to be developed which demonstrates elements that need to be considered during the environmental risk assessment.

3.2.4 Medicinal products

The authorisation of medicinal products for human use in the EU is regulated by the revised version of the Directives 2001/83/EC and their national transpositions. In 2019, the directive for veterinary medicinal products 2001/82 EC was replaced by the EU regulation 2019/6 of the European Parliament and of the Council in 2019, which is applicable as of 2022. Based on both legal provisions, the potential environmental risk posed by a medicinal product is to be assessed and inspected for harmful environmental impacts. According to both provisions, there are currently no binding requirements for nanoscale substances within authorisation of medicinal products[81].

Under the working definition of the European Medicines Agency (EMA), nanomaterials include a wide spectrum of nanoscale substances. In addition to active substances that have been reduced to nanoscale size by physical activity (grinding), there are also (modified) proteins, peptides and oligonucleotides, and liposomes, (co)polymer particles, dendrimers, carbon- or silicon-based nanoparticles, and metal- or metal oxide- nanoparticles[82]. In contrast, the definition proposed by the European Commission explicitly excludes medicinal products.

Nanoscale substances can be used to transport an active substance in patients. The use of nanoscale formulations in this area is expected to offer improved availability, better targeted and controlled release at the desired location, and reduced side-effects. For example, nanomaterials could be used in cancer therapy to increase the effectiveness of radiotherapy and chemotherapy. In diagnostics and medical imaging procedures, nanomaterials are used in contrast agents and in Lab-on-a-chip technology[83].

For medicinal products for human use, the result of the environmental assessment is not relevant for the authorisation, but measures to reduce the environmental risk can be included in the summary product information and the package leaflet. For veterinary medicinal products, the outcome of the environmental risk assessment is included in the final evaluation of the benefits and risks for the product authorisation. It is the duty of the manufacturer to supply information about the environmental risk assessment when applying for marketing authorisation. The first step is to estimate the environmental exposure for a preparation. Only in case a defined threshold is exceeded or the preparation belongs to a certain group of active substances, it becomes necessary to submit information about the behaviour and effects in the environment (second phase of assessment). An environmental risk assessment is provided for the active substance. Other components, such as co-formulants, are not included in the environmental risk assessment.

In case of a second phase assessment an in-depth environmental risk assessment is performed, which involves the collection of physical and chemical data and data on environmental behaviour and effects. This approach was developed for low-molecular medicinal products, but in some respects, it proves to be inadequate for the evaluation of nanoscale active substances[84]. It is therefore necessary to consider whether the current approach using a threshold based on mass concentration is adequate for nanoscale active substances in view of their potentially increased activity. Adaptations to the threshold may be necessary.

The guidance document for the environmental risk assessment of human medicinal products does not include any advice on how to deal with nanoscale active substances. In the opinion of UBA, nanoscale active substances in medicinal products should be subjected to a specific assessment. The guidance document should therefore include a definition for nanoscale active substances. As some of the test methods and strategies recommended in the draft guidance are not suitable to assess nanoscale active

substances, a tailored risk assessment of these substances is needed, as it is already performed for e. g. endocrine substances. Such a tailored assessment should consider appropriate studies on physical chemical characterisation, on ecotoxicological endpoints and endpoints on environmental fate which are of special relevance for nanomaterials, e. g. dispersion stability and dissolution rate in relevant environmental media.

The current guidance document does not include an assessment of co-formulants, so that there is also no specific identification and assessment of nanoscale co-formulants. However, it can be assumed that nanomaterials are already being used[85]. UBA appraises that the use of nanomaterials as co-formulants, e. g. in medicinal products, contributes to the entry of nanomaterials into the environment. In order to obtain a better quantitative and qualitative overview of this entry, UBA sees the usefulness to require specific details of nanoscale co-formulants when applying for authorisation of medicinal products.

For the EU Regulation on veterinary medicinal products, which is applicable as from January 2022, adaptions of the annex II of the regulation are currently discussed. This annex shall specify technical requirements for presenting quality, safety and efficiency of active substances, for which market authorisation is intended. For this annex, EMA presented recommendations for adaptions to the European Commission[86].

These recommendations *inter alia* include advice how to deal with veterinary medicinal products manufactured using nanotechnology, in particular for use in drug delivery systems. Based on these recommendations, particle size distributions should be determined for nanoscale substances. Furthermore, changes in toxicology, distribution within the patient's body and side effects of the veterinary medicinal product should be determined. However, proposals how to consider nanoscale substances within environmental risk assessment of veterinary medicinal products were not included in EMA's recommendations. For environmental risk assessment, annex II is referring to the respective guidance documents of EMA. Therefore, in the view of UBA, appropriate information requirements on ecotoxicity and environmental fate of nanomaterials used in veterinary medicinal products should become part of these guidance documents.

In the opinion of UBA, nanoscale active substances in medicinal products should undergo an adapted environmental risk assessment. This should be carried out on basis of suitable data on physical-chemical characterisation as well as environmental behaviour and effects.

3.3. Register for products containing nanomaterials

There is no consistent picture of nanomaterials in products on the European Market. Only a few of the products containing nanomaterials are covered by specific legal requirements (e. g. biocidal substances, cosmetics, plastics as food contact materials, novel food, food additives).

Because requirements for declaration and notification for nanomaterials are largely missing, the lack of knowledge about their use in products affects not only consumers but also the regulatory authorities. The REACH regulation cannot remedy that situation because it applies primarily for substances and mixtures. In addition, the regulation does not in general include obligations to report on the composition of individual products.

There are already a number of databases and platforms on nanomaterials and their products (e. g. ANEC/BEUC List, Online Database of BUND)[87]. A comprehensive data base is offered by the knowledge base of DaNa 4.0[88]. These databases serve a wide range of purposes and draw on information of varying quality from different sources, so that they provide an inconsistent and incomplete picture.

Due to the lack of transparency about the types, amounts and applications of nanomaterials, an estimate of the exposure and thus an assessment of the potential risks posed for humans and the

environment is only possible to a very limited extent. Therefore, at an early stage, discussions about setting up a product register for nanomaterials and products containing nanomaterials started at the European level.

The aim of such a register and the associated reporting obligations is to provide the authorities with an overview of the products containing nanomaterials that are produced in Europe or are available on the EU Single Market. It should also increase the transparency for consumers.

France, Denmark, Belgium, but also Norway and Sweden, have introduced national reporting obligations for nanomaterials and products containing nanomaterials, respectively[89]. These have differing orientations, regulatory objectives and intentions. All of these Member States would prefer a European approach but have decided on a national register because a European instrument is not yet in sight.

Already in June 2012, the UBA published a proposal for a trans-sectoral European register of products containing nanomaterials, which is based on existing regulations, complemented by further provisions, and brings together the information obtained from these regulations[90]. In addition to substances and mixtures, products for which release of nanomaterials over their life cycle cannot be excluded should also be included. Such a register would be used first of all by regulatory authorities. For reasons of transparency, in its concept UBA also proposes making parts of the data available to the general public. A European register would lead to less distortion of competition than various national register[91].

In 2017, the European Commission launched an European Union Observatory for Nanomaterials (EU-ON) situated at ECHA[92]. The EU-ON aims to collect available information on nanomaterials on the European market and to process and publish it for target groups. The establishment of the EU-ON has been seen critically by various actors, as it only features a minimal solution.

Several member states established national registers for nanomaterials or products containing nanomaterials with differing focus, provisions and intentions. An European register for products containing nanomaterials still not exists. The European Union Observatory for Nanomaterials gathers available information on nanomaterials on the European market and processes them for target groups. In view of UBA, the information within EU-ON are currently limited to reach the goal of transparency concerning the types, amounts and applications of nanomaterials on the European market.

3.4 Eco-labelling

Eco-labelling should offer consumers guidance for identifying and choosing more environmentally-friendly products and services over a broad range of products, in order to promote environmentally beneficial product innovations and to reduce environmental pollution. Eco-labelling is backed up by a number of instruments and methods which are deployed in order to check whether a product meets the environmental quality requirements.

In 2009, the UBA argued against awarding the 'Blue Angel' label to products containing manufactured nanomaterials, drawing attention to unresolved issues relating to the health risk and environmental risks[93].

With the presentation of the broad EU definition recommendation in October 2011, it quickly became clear that many products contain nanomaterials and some of these materials have been in use for decades (see section 3.1.1). On the basis of the knowledge gained in recent years, there are no scientific grounds to generally disqualify products with nanomaterials from receiving environmental quality labels. At the same time, it is not possible to assume that all nanomaterials are without risks; for many nanomaterials gaps remain in the knowledge about their hazard potentials. These uncertainties cannot be ignored when awarding eco-labelling, and nanomaterials must be dealt with in a way which pays due attention to environmental and health protection.

In principle, the German and EU eco-labelling exclude substances with certain toxic and ecotoxic properties – to a greater or lesser extent depending on the product group in question. This applies in the same way for nanomaterials. Under the CLP Regulation, substances must be classified and labelled according to the form in which they are used, i. e. corresponding to the nanoform used. Therefore, all information needs to be gathered which is appropriate for the particular form. If the nanoform of a substance has critical properties (e. g. it is carcinogenic or highly toxic for aquatic organisms), then, like other substances with these properties, it will be excluded from eco-labelling. In order to ensure that the test data relate to the nanoform of the substance, in the case of relevant product groups when presenting the safety data sheets for substances which are solid under normal conditions, it is necessary to transparently outline nanoscale forms. With the amendment of annex II of the REACH regulation the foundation is laid to achieve this transparency.

In addition, there is the possibility of explicitly disqualifying products containing specific nanomaterials from the eco-labelling if the benefits of the nanomaterial are questionable or other negative effects on humans and the environment cannot be excluded. For example, this is the case for nanoscale silver in products such as refrigerators and telephones. The decision is taken for specific product groups and discussed with all affected interest groups at the expert meetings on the award principles.

In the view of UBA, it is necessary to indicate together with the submission of the safety data sheet for a substance in a relevant product category whether or not the substance comprises nanoscale forms. Applicable as from 1 January 2021 (with a transition period until 31 December 2022) safety data sheets need to describe precisely whether and for which nanoforms of the substance the information relates to.

4. Activities of the Federal Environment Agency

The German Environment Agency provides information on environmentally-relevant aspects of nanotechnology, aims to fill gaps in knowledge and to determine needs for action. It supports the responsible use of nanomaterials by actively participating in the discussions on taking account of the special characteristics of nanomaterials in the legislations on chemical safety at national, European and international levels.

One of the focal points of the work of the German Environment Agency is the assessment of the risks posed by nanomaterials for the environment. The Agency has been active since 2006 in the OECD Working Party on Manufactured Nanomaterials (WPMN). The current focus of the UBA relates to the development of OECD test guidelines and guidance documents for the appropriate investigation of the behaviour and effects of nanomaterials in the environment. In the OECD Working Party on Resource Productivity and Waste (WPRPW), the UBA is involved in tackling environmentally relevant questions concerning the disposal of waste containing nanomaterials.

A further field of activity of the UBA is the adaption of legislation to meet the requirements concerning nanomaterials. In various working groups, e. g. the Nanomaterial Expert Group of ECHA, UBA participates in discussions on adapting the regulations and risk assessment for nanomaterials. The involvement of UBA in national and international committees on the topic is presented in the Annex in Table 1. Within the NanoDialogue of the Federal Government, UBA contributes with expertise to selected topics of thematic dialogue meetings. Together with other higher federal authorities in Germany (BAuA, BfR, Federal Institute for Materials Research and Testing (BAM), National Metrology Institute (PtB)), UBA has formulated a research strategy on the risks to health and the environment posed by nanomaterials; this is revised periodically in accordance with the latest research requirements[94]. To implement this

strategy, UBA initiates and supervises various research projects (Table 2 in the Annex). The Agency also participates in various national and European third-party funded projects on the topic, and among other things provides connections to regulatory and political bodies (Table 3 in the Annex).

Information about the work of UBA and its research activities, together with further information and links to nanotechnology topics can be found on the UBA website[95].

5. Summary and recommendations

The nanoscale form of a substance does not necessarily constitute a hazard or risk. However, nanomaterials have specific properties that distinguish them from other chemicals. The knowledge about characteristics, behaviour, and effects of nanomaterials gained during the last years allows it already now to identify which aspects are needed for the testing and assessment of their environmental risks and have to be reflected in the regulatory requirements.

In the opinion of UBA, key measures in the framework of chemical safety to adequately depict and assess the nanomaterial specific environmental risks as well as to take appropriate measures for risk minimisation are:

- Implementation of a harmonised definition of nanomaterials in the various regulations on the safety of chemicals
- Addition of missing nano-specific requirements in the regulations of biocidal products and plant protection products, the directive on human medicinal products, and the regulation on veterinary medicinal products
- Continuing the adaption of the guidelines, models, and concepts for hazard and risk assessment in the framework of the different regulations on chemical safety to provide appropriate environmental risk assessment for nanomaterials
- Continuing the adaption of the instruments for environmental risk assessment, above all the development of nanomaterial specific test guidelines and guidance documents for testing of environmental behaviour and effects, and the physical and chemical properties
- Continuing the standardisation of methods for qualitative and quantitative analytics for nanomaterials in the environment
- Using the information relating to the relevant nanoform for classification in hazard classes and categories
- Improved transparency on nanomaterials within the supply chain and in products on the European market.

These measures follow also the SAICM[96] resolution of the 4th international conference on chemical management (ICCM4) in Geneva in regards to the encouragement to adequately consider manufactured nanomaterials in national and international regulatory instruments[97].

With regard to the implementation and further development of the regulations of concern and the required risk assessment instruments, UBA will continue to cooperate closely with the other assessment and authorisation bodies in Germany (BAuA, BfR, BfArM, BVL), the Federal Office for Chemicals, the Federal Ministry of the Environment as well as the representatives of the other European Member states, the European Chemical Agency ECHA, the European Food Safety Agency EFSA, the European Medicine Agency EMA, the European Commission and the OECD. The nanomaterials research strategy developed in cooperation with other higher federal authorities (BAuA, BfR, BAM, PtB) is still being pursued. The steady progress of advancement of nanomaterials has to be observed carefully in order to ensure that the adaptations of individual instruments for risk assessment currently being called for and discussed will still be adequate in the future. This also accounts for the consideration of advanced materials, for which similar challenges regarding risk assessment in the framework of chemical safety have to be expected.

6. Publications of UBA employees since 2009

UBA (2009): Background Document: Nanotechnology for humans and the environment (available on the UBA website).

BfR & UBA (2010): Beurteilung eines möglichen Krebsrisikos von Nanomaterialien und von aus Produkten freigesetzten Nanopartikeln. Stellungnahme des Bundesinstituts für Risikobewertung und des Umweltbundesamtes vom 15. April 2010. (available on the UBA website).

Dubbert, W. (2010): Risiken durch Nanotechnologie? Langzeitwirkungen nur unzureichend erforscht. Personal Protection & Fashion PPF No. 1 February 2010, p. 58.

Becker, H., Herzberg, F., Schulte, A., Kolossa-Gehring, M. (2011): The carcinogenic potential of nanomaterials, their release from products and options for regulating them. Int. J. Hyg. Environ. Health **214**(3): 231–238.

Becker, H., Kolossa-Gehring, M., Herzberg, F., Schulte, A. (2011): Response to Letter to the Editor. Int. J. Hyg. Environ. Health **214** (5):412.

BMU IG II 6, UBA III 2.3 K (2010): Nanomaterialien für den Umweltschutz – Besser als herkömmliche Produkte? Umwelt, **6**/2010, p. 366.

BMU IG II 6, UBA III 2.3 K (2010): Emissionen von Nanomaterialien aus Produkten – Vollständige Bewertung derzeit noch nicht möglich. Umwelt, **12**/2010, p. 754.

Dhawan, A., Shanker, R., Laffon, B., Tajes, J. F., Fuchs, D., van der Laan, G., van Broekhuizen, P., Becker, H., Moriske, H. J., Teixeira, J. P., Carriere, M., Herlin-Boime, N., Engin, A. B., Coskun, E., Karahalil, B. (2011): NanoLINEN: Nanotoxicology link between India and European Nations. J Biomed Nanotechnol. 7(1): 203–204.

Dubbert, W. und H. Becker (2011): Emissionen von Nanopartikeln aus Produkten. Umwelt und Mensch – Informationsdienst 3/2011, pp. 25–29.

BMU IG II 6 und UBA III 2.1 (2012): Kleinste Teile mit großer Wirkung – Eine neu entwickelte Methode für Hersteller zur internen Überprüfung des nachhaltigen Nutzens von Nanoprodukten: der Nano-Nachhaltigkeits-Check. Umwelt **5**/2012, pp. 40–41.

Dubbert, W., Schwirn, K., Völker, D. (2012): Nanomaterials in sunscreens: impacts on the environment? UMID **2**/2012, pp. 41–45. (Available on the UBA website).

Schäfer, B., Blume, A., Peiser, M., Apel P., Platzek, T. (2012): Schönheit ohne Risiko – Aktuelle Probleme bei der Bewertung von Sonnenschutzfilter-Substanzen in der EU, UMID **2**/2012, pp. 35–40.

Wiechmann, B., Dubbert, W. und V. Weiss (2012): Winzige Stolpersteine. Recycling Magazin **01**/2012, pp. 32–34.

UBA (2010): Micro pollutants: Nanomaterialien. In: Water Resource Managment in Germany, Part 1: Fundamentals. BMUB. pp. 93–94. (available on the UBA website). Second edition in 2014.

UBA (2012): Concept for a European Register of Products Containing Nanomaterials. (available on the UBA website).

UBA (2013): Fact sheet nano products: Use of Nanoscale Iron for the Remediation of Groundwater Damages. (available on the UBA website).

UBA (2013): Fact sheet nano products: Use of Nanomaterials in Textiles. (available on the UBA website).

UBA (2013): Fact sheet nano products: Nanotechnology-based lighting systems: organic light-emitting diods (OLED). (available on the UBA website).

UBA, BfR, BAuA (2013): Nanomaterials and REACH – Background Paper on the Position of German Competent Authorities. (available on the UBA website).

UBA, BfR, BAuA, BAM, PTB (2013): First Evaluation on the Joint Research Strategy of German Governmental Research Institutions „Nanotechnology – Risk related Nanomaterials for Humans and the Environment“ (2007–2011). (available on the UBA website).

BMU IG II 6, UBA III 2.1 (2013): Eine eisenhaltige Methode. BMU-Umwelt **3**/2013, p. 43.

UBA FG IV2.2, BMU IG II 6 (2013): Umweltwirkung von Nanomaterialien, BMU Umwelt **5**/2013, pp. 58–60.

BMUB WR III 4, UBA III 2.1 (2014): Winzige Hoffnungsträger – Lassen sich mit Nanotechnik Energie und Rohstoffe einsparen? BMUB-Umwelt **4**/2014, p. 47.

OECD Environment Directorate (2014): Ecotoxicology and environmental fate of manufactured nanomaterials: test guidelines. Expert Meeting Report. Series on the Safety of Manufactured Nanomaterials No. 40 (ENV/JM/MONO(2014)1). Online on the OECD website.

Schwirn, K., Tietjen, L., Beer, I. (2014): Why are nanomaterials different and how can they be appropriately regulated under REACH? Envion Sci Eur **26**(1): 4.

UBA (2014): Schlussbericht zum BMBF-Projekt UMSICHT – Abschätzung der Umweltgefährdung durch Silbernanomaterialien. Online on the website of Technische Informationsbibliothek Hannover.

UBA (2014). Fact sheet nano products: Use of nanomaterials in coatings. (available on the UBA website).

UBA FG IV2.2, Universität Bremen, BMU IG II 6 (2014): Nanosilber in Textilien: Segen oder Sicherheitsrisiko? BMUB Umwelt **7–8**/2014, pp. 17–19.

UBA (2015) Fact sheet nano products: The Use of Nanomaterials in energy storage. (available on the UBA website).

Voelker, D., Schlich, K., Hohndorf, L., Koch, W., Kühnen, U., Polleichtner, C., Kussatz, C., Hund-Rinke, H. (2015). Approach on environmental risk assessment of nanosilver released from textiles. Environ Res **140**(0): 661–672.

Berkner, S., Schwirn, K., Voelker, D. (2015). Nanopharmaceuticals – tiny challenges for the environmental risk assessment of pharmaceuticals. Environmental Toxicology and Chemistry **35**(4): 780–787.

Hund-Rinke, H., Herrchen, M., Schlich, K., Schwirn, K., Voelker, D. (2015). Test strategy for assessing the risks of nanomaterials in the environment considering general regulatory procedures. Environ Sci Eur **27**, 24.

UBA (2015). Fact sheet nano products: Use of nanomaterials and nanoscale products for wastewater treatment. (available on the UBA website).

UBA (2016). Datenblatt Nanoprodukte: Einsatz von Nanomaterialien in der Stromerzeugung aus erneuerbaren Energien. (available on the UBA website).

UBA, BfR, BAuA, BAM, PTB (2016). Nanomaterials and other advanced materials: application safety and environmental compatibility - Review of the joint research strategy of the higher federal authorities. (available at UBA website).

Schwirn, K., Voelker D. (2018). Nanotechnologie: Kleinste Teilchen – große Herausforderung. Umwelt aktuell **03** 2018, pp. 8–9. https://www.dnr.de/fileadmin/Publikationen/umwelt_aktuell/ua2018-03.pdf.

UBA (2018). Conference Report: Scientific Stakeholder Meeting on Nanomaterials in the Environment (available on the UBA website).

UBA (2018). Datenblatt Nanoprodukte: Einsatz von Nanomaterialien in Kunststoffverpackungen (available on the UBA website).

Degenkolb, L., Metreveli, G., Philippe, A., Brandt, A., Leopold, K., Zehlike, L., Vogel, H. J., Schaumann, G. E., Baumann, T., Kaupenjohann, M., Lang, F., Kumahor, S., Klitzke, S. (2018). Retention and remobilization mechanisms of environmentally aged silver nanoparticles in an artificial riverbank filtration system. Sci Total Environ. **645**:192–204.

Dippon, U., Pabst, S., Klitzke, S. (2018). Colloidal stabilization of CeO 2 nanomaterials with polyacrylic acid, polyvinyl alcohol or natural organic matter. Science of The Total Environment. **645**:1153–58.

UBA (2018): Schlussbericht zum BMBF-Projekt DENANA – Designkriterien für nachhaltige Nanomaterialien. Online on the website of Technische Informationsbibliothek Hannover.

UBA (2019): Schlussbericht zum BMBF-Projekt nanoGRAVUR- Nanostrukturierte Materialien – Gruppierung hinsichtlich Arbeits-, Verbraucher- und Umweltschutz und Risikominimierung. Online on the website of Technische Informationsbibliothek Hannover.

Degenkolb, L., Klitzke, S., Kaupenjohann, M. (2019). The variable fate of Ag and TiO2 nanoparticles in natural soil solutions – sorption of organic matter and nanoparticle stability. Water, Air, and Soil Pollution. **230** (3): 62.

Zehlike, L., Peters, A., Ellerbrock, R. H., Degenkolb, L., Klitzke, S. (2019). Aggregation of TiO2 and Ag nanoparticles in soil solution – Effects of primary nanoparticle size and dissolved organic matter characteristics. Sci Total Environ. **688**:288–98.

Degenkolb, L., Dippon, U“ Pabst, S“ Klitzke, S,. (2019). Transport and retention of differently coated CeO2 nanoparticles in saturated sediment columns under laboratory and near-natural conditions. Environ Sci Pollut Res Int. **26**: 15905–15919.

Kühnel, D., Nickel, C., Hellack, B., Van der Zalm, E., Kussatz, C., Herrchen, M., Meisterjahn, B., Hund-Rinke, K. (2019). Closing gaps for environmental risk screening of engineered nanomaterials. NanoImpact **15**: 100173.

Schwirn, K., Völker, D. (2019). Hazard grouping of nanomaterials for daphnia and algae toxicity: lessons learned from scientific projects for regulatory applicability. Environ Sci Eur **31**(1): 48.

Kuehr, S., Meisterjahn, B., Schröder, N., Knopf, B., Völker, D., Schwirn, K., Schlechtriem, C. (2020). Testing the bioaccumulation of manufactured nanomaterials in the freshwater bivalve Corbicula fluminea using a new test method. Environ. Sci.: Nano **7**: 535–553.

Degenkolb, L., Leuther, F., Luderwald, S., Philippe, A., Metreveli, G., Amininejad, S., Vogel, H. J., Kaupenjohann, M., Klitzke, S. (2020). The fate of silver nanoparticles in riverbank filtration systems – The role of biological components and flow velocity. Sci Total Environ. **699:**134387.

Schwirn, K., Voelker, D., Galert, W., Quik, J., Tietjen, L. (2020). Environmental Risk Assessment of Nanomaterials in the light of new obligations under the REACH regulation – Which challenges remain and how to approach them? Integr Environ Assess Manag **2020**: 1–12.

7. Endnotes

1. The present document uses the definition of nanomaterials proposed by the EU Commission, October 2011: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:275:0038:0040:EN:PDF with reference to technically produced nanomaterials.

2. Umweltbundesamt (2009). Nanotechnology for humans and the environment – Promote opportunities and reduce risk. https://www.umweltbundesamt.de/publikationen/nanotechnology-for-humans-environment

3. Khare, P., et al. (2015). „Size dependent toxicity of zinc oxide nano-particles in soil nematode Caenorhabditis elegans." Nanotox **9**: 423–432.; Rogers, N. J., et al. (2010). „Physico-chemical behaviour and algal toxicity of nanoparticulate CeO2 in freshwater." Environ Chem **7**: 50–60.; Silva, T., et al. (2014). „Particle size, surface charge and concentration dependent ecotoxicity of three organo-coated silver nanoparticles: Comparison between general linear model-predicted and observed toxicity." Sci Tot Environ **468–469**: 968–976.; Gorka D. E., et al. (2015). „Reducing environmental toxicity of silver nanoparticles through shape control." Environ Sci Technol **49**: 10093–10098.; George, S., et al. (2012). „Surface defects on plate-shaped silver nanoparticles contribute to its hazard potential in a fish gill cell line and zebrafish embryos." ACS Nano **6**: 3745–3759.

4. Kennedy, A. J., et al. (2012). „Impact of organic carbon on the stability and toxicity of fresh and stored silver nanoparticles." Environ Sci Technol **46**: 10772–10780.; Tejammaya, M., et al. (2012). „Stability of citrate, PVP, and PEG coated silver nanoparticles in ecotoxicology media." Environ Sci Technol **46**: 7011–7017.; Unrine, J. M., et al. (2012). „Biotic and abiotic interactions in aquatic microcosms determine fate and toxicity of Ag nanoparticles. Part 1. Aggregation and Dissolution." Environ Sci Technol **46**: 6915–6924.; Ottofuelling, S., et al. (2011). „Commercial titanium dioxide nanoparticles in both natural and synthetic water: comprehensive multidimensional testing and prediction of aggregation behavior." Environ Sci Technol **45**: 10045–10052.

5. Ma, H., et al. (2013). „Ecotoxicity of manufactured ZnO nanoparticles – a review." Environ Pollut **172**: 76–85.; Asghari, S., et al. (2012). „Toxicity of various silver nanoparticles compared to silver ions in Daphnia magna." J Nanobiotechnol **10**(14): 1–14.

6. Notter, D. A., et al. (2014). „Are nanosized or dissolved metals more toxic in the environment? A Meta-Analysis." Environ Tox Chem **33**: 2733–2739.; Gil-Allué, C., et al. (2015). „Silver Nanoparticle Effects on Stream Periphyton During Short-Term Exposure." Environ Sci Technol **49**: 1165–1172.; Li, L., et al. (2015). „Both released silver ions and particulate Ag contribute to the toxicity of AgNP to earthworm Eisenia fetida." Nanotox **9**: 792–801.

7. Ma, H., et al. (2012). „Phototoxicity of TiO_2 nanoparticles under solar radiation to two aquatic species: Daphnia magna and Japanese medaka." Environ Toxicol Chem **31**(7): 1621–1629.

8. Smith C. J.et al. (2007). „Toxicity of single walled carbon nanotubes to rainbow trout, (*Oncorhynchus mykiss*): Respiratory toxicity, organ pathologies, and other physiological effects." Aquat Toxicol **82**(2):94–109.; Griffitt, R. J., et al. (2007). „Exposure to Copper Nanoparticles Causes Gill Injury and Acute Lethality in Zebrafish (Danio rerio)." Environ Sci Technol **41**(23): 8178–8186.; Choi, J. E., et al. (2010). „Induction of oxidative stress and apoptosis by silver nanoparticles in the liver of adult zebrafish." Aquat Toxicol **100**(2): 151–159.; Jovanovic, B., et al. (2014). „Histopathology of fathead minnow (Pimephales promelas) exposed to hydroxylated fullerenes." Nanotoxicol **8**(7): 755–763.

9. Li, M., et al. (2011). „Responses of Ceriodaphnia dubia to TiO_2 and Al_2O_3 nanoparticles: a dynamic nano-toxicity assessment of energy budget distribution.“ J Hazard Mater **187**(1–3): 502–508.; Boyle, D., et al. (2013). „Subtle alterations in swimming speed distributions of rainbow trout exposed to titanium dioxide nanoparticles are associated with gill rather than brain injury.“ Aquatic Toxicology **126**: 116–127.; Mattsson, K., et al. (2015). „Altered behavior, physiology, and metabolism in fish exposed to polystyrene nanoparticles.“ Environ Sci Technol **49**(1): 553–561.; Cedervall, T., et al. (2012). „Food chain transport of nanoparticles affects behaviour and fat metabolism in fish.“ PLoS One **7**(2): e32254.; Pradhan, A., et al. (2015). „Natural organic matter alters size-dependent effects of nanoCuO on the feeding behaviour of freshwater invertebrate shredders.“ Sci Total Environ **535**: 94–101.

10. Völker, C., et al. (2013). „Comparative toxicity assessment of nanosilver on three Daphnia species in acute, chronic and multi-generation experiments.“ PLoS One **8**(10): e75026.; Jacobasch, C., et al. (2014). „Long-term effects of nanoscaled titanium dioxide on the cladoceran Daphnia magna over six generations.“ Environ Pollut **186**: 180–186. Kim, S. W., et al. (2013). „Multigenerational study of gold nanoparticles in Caenorhabditis elegans: transgenerational effect of maternal exposure.“ Environ Sci Technol **47**(10): 5393–5399.

11. Shoults-Wilson, W. A., et al. (2011). „Evidence for avoidance of Ag nanoparticles by earthworms (Eisenia fetida).“ Ecotoxicol **20**(2): 385–396.; McShane, H., et al. (2012). „Reproductive and behavioral responses of earthworms exposed to nano-sized titanium dioxide in soil.“ Environ Toxicol Chem **31**(1): 184–193.

12. Schlich, K., et al. (2012). „Effect of TiO_2 nanoparticles in the earthworm reproduction test.“ Environ Sci Eur **24**(1): 5.; Shoults-Wilson, W. A., et al. (2011). „Effect of silver nanoparticle surface coating on bioaccumulation and reproductive toxicity in earthworms (Eisenia fetida).“ Nanotoxicol **5**(3): 432–444.

13. Khodakovskaya, M., et al. (2015). „Carbon Nanotubes Are Able To Penetrate Plant Seed Coat and Dramatically Affect Seed Germination and Plant Growth.“ ACS Nano **3**(10): 3221–3227.; Wang, P., et al. (2015). „Silver sulfide nanoparticles (AgS-NPs) are taken up by plants and are phytotoxic.“ Nanotoxicol: 1–9.; Hong, J., et al. (2014). „Evidence of translocation and physiological impacts of foliar applied CeO2 nanoparticles on cucumber (Cucumis sativus) plants.“ Environ Sci Technol **48**(8): 4376–4385.

14. Ge, Y., et al. (2011). „Evidence for Negative Effects of TiO_2 and ZnO Nanoparticles on Soil Bacterial Communities.“ Environ Sci Technol **45**(4): 1659–1664.

15. Starnes, D. L., et al. (2015). „Impact of sulfidation on the bioavailability and toxicity of silver nanoparticles to Caenorhabditis elegans.“ Environ Pollut **196**: 239–246.; Wang, P., et al. (2015). „Silver sulfide nanoparticles (Ag2S-NPs) are taken up by plants and are phytotoxic.“ Nanotoxicology **9**(8): 1041–1049.; Schlich, K. & K. Hund-Rinke (2015). „Influence of soil properties on the effect of silver nanomaterials on microbial activity in five soils.“ Environ Pollut **196**: 321–330.

16. Hartmann, N. B., et al. (2012). „The challenges of testing metal and metal oxide nanoparticles in algal bioassays: titanium dioxide and gold nanoparticles as case studies.“ Nanotoxicol **7**(6): 1082–1094.; Jacobasch, C., et al. (2014). „Long-term effects of nanoscaled titanium dioxide on the cladoceran Daphnia magna over six generations.“ Environ Pollut **186**: 180–186.

17. Sun, H., et al. (2007). „Enhanced Accumulation of Arsenate in Carp in the Presence of Titanium Dioxide Nanoparticles.“ Water, Air, & Soil Pollut **178**(1): 245–254.; Ferguson, P. L., et al. (2008). „Influence of sediment-amendment with single-walled carbon nanotubes and diesel soot on bioaccumulation of hydrophobic organic contaminants by benthic invertebrates.“ Environ Sci Technol **42**(10): 3879–3885.; Tan, C., et al. (2012). „Role of titanium dioxide nanoparticles in the elevated uptake and retention of cadmium and zinc in Daphnia magna.“ Environ Sci Technol **46**(1): 469–476.; Schwab, F., et al. (2013). „Diuron sorbed to carbon nanotubes exhibits enhanced toxicity to Chlorella vulgaris.“ Environ Sci Technol **47**(13): 7012–7019.

18. Erhardt, E. (2003) „Not-so-new technology.“ Nature Materials Vol. 2.

19. Hermann, A. et al. (2013) „Assessment of impacts of a European register of products containing nanomaterials“ http://www.umweltbundesamt.de/publikationen/assessment-of-impacts-of-a-european-register-of

20. Kaegi, R., et al. (2008). „Synthetic TiO_2 nanoparticle emission from exterior facades into the aquatic environment.“ Environ Pollut **156**(2): 233–239.; Shandilya, N., et al. (2015). „Emission of titanium dioxide nanoparticles from building materials to the environment by wear and weather.“ Environ Sci Technol **49**(4): 2163–2170.; Geranio, L., et al. (2009). „The Behaviour of Silver Nanotextiles during Washing.“ Environ Sci Technol **43**: 8113–8118.; Lorenz, C., et al. (2012). „Characterization of silver release from commercially available functional (nano)textiles.“ Chemosphere **89**(7): 817–824.

21. Gondikas, A. P., et al. (2014). „Release of TiO_2 nanoparticles from sunscreens into surface waters: a one-year survey at the old Danube recreational Lake.“ Environ Sci Technol **48**(10): 5415–5422.; UBA (2012): Fact Sheet nano products: Use of nanoscaled iron for the remediation of groundwater damages. https://www.umweltbundesamt.de/publikationen/use-of-nanoscale-iron-for-the-remediation-of; UBA (2015). Fact Sheet nano products: Use of nanomaterials and nanoscale products for wastewater treatment. https://www.umweltbundesamt.de/en/publikationen/use-of-nanomaterials-nanoscale-products-for

22. Goehler, D. et al. (2010) „Characterisation of nanoparticle release from surface coatings by the simulation of a sanding process.“ Ann Occup Hyg **54**(6): 615–624.

23. Gómez-Rivera, F., et al. (2012). „Fate of cerium dioxide (CeO_2) nanoparticles in municipal wastewater during activated sludge treatment.“ Biores Technol 108: 300–304.; Wang, Y., et al. (2012). „Fate and biological effects of silver, titanium dioxide, and C60 (fullerene) nanomaterials during simulated wastewater treatment processes.“ J Hazard Mater **201202**: 16–22.

24. Walser, T. et al. (2012) „Persistence of engineered nanoparticles in a municipal solid waste incineration plant.“ Nat Nanotech 7: 520–524.; Börner, R. et al. (2016). „Untersuchung möglicher Umweltauswirkungen bei der Entsorgung nanomaterialhaltiger Abfälle in Abfallbehandlungsanlagen.“ UBA TEXTE 37/2016, https://www.umweltbundesamt.de/publikationen/untersuchung-moeglicher-umweltauswirkungen-bei-der

25. Kaegi, R. et al. „Release of (nanoscale)-TiO_2 particles from landfills.“ PB14, Poster 10th International Conference on the Environmental Effects of Nanoparticles and Nanomaterials (ICEENN 2015).

26. Hartmann et al. „Environmental fate and behavior of nanomaterials – New knowledge on important transformation processes.“ Environmental Project No. 1594 of the Danish Environmental Protection Agency (2014).

27. Cornelis et al. (2013). „Transport of silver nanoparticles in saturated columns of natural soils.“ Sci Tot Environ **463–464**: 120–130.

28. Hou, W. C., et al. (2013). „Biological accumulation of engineered nanomaterials: a review of current knowledge.“ Environ Sci Process Impacts **15**(1): 103–122.

29. Hu, J., et al. (2012). „Bioaccumulation of Fe_2O_3(magnetic) nanoparticles in Ceriodaphnia dubia.“ Environ Pollut **162**: 216–222.; Lovern, S. B., et al. (2009). „Electron microscopy of gold nanoparticle intake in the gut of Daphnia magna.“ Nanotoxicology **2**(1): 43–48.

30. Sun, H., et al. (2009). „Influence of titanium dioxide nanoparticles on speciation and bioavailability of arsenite.“ Environ Pollut **157**(4): 1165–1170.; Zhu, X., et al. (2010). „Trophic transfer of TiO(2) nanoparticles from Daphnia to zebrafish in a simplified freshwater food chain.“ Chemosphere **79**(9): 928–933.; Gaiser, B. K., et al. (2012). „Interspecies comparisons on the uptake and toxicity of silver and cerium dioxide nanoparticles.“ Environ Toxicol Chem **31**(1): 144–154.

31. Maes, H. M., et al. (2014). „Accumulation and distribution of multiwalled carbon nanotubes in zebrafish (Danio rerio).“ Environ Sci Technol **48**(20): 12256–12264.

32. Hu, C., et al. (2010). „Toxicological effects of TiO_2 and ZnO nanoparticles in soil on earthworm Eisenia fetida.“ Soil Biol Biochem **42**: 586–591.; Coleman, J. G., et al. (2010). „Assessing the fate and effects of nano aluminum oxide in the terrestrial earthworm, Eisenia fetida.“ Environ Toxicol Chem **29**(7): 1575–1580.

33. Schwab, F., et al. (2015). „Barriers, pathways and processes for uptake, translocation and accumulation of nanomaterials in plants – Critical review.“ Nanotoxicol: 1–22.

34. Ward, J. E. and D. J. Kach (2009). „Marine aggregates facilitate ingestion of nanoparticles by suspension-feeding bivalves.“ Mar Environ Res **68**(3): 137–142.; Hull, M. S., et al. (2011). „Filter-feeding bivalves store and biodeposit colloidally stable gold nanoparticles.“ Environ Sci Technol **45**(15): 6592–6599.; Conway, J. R., et al. (2014). „Effects and implications of trophic transfer and accumulation of CeO_2 nanoparticles in a marine mussel.“ Environ Sci Technol **48**(3): 1517–1524.

35. Kettler, K., et al. (2014). „Cellular uptake of nanoparticles as determined by particle properties, experimental conditions, and cell type.“ Environ Toxicol Chem **33**(3): 481–492; Treuel, L., et al. (2013). „New views on cellular uptake and trafficking of manufactured nanoparticles.“ J R Soc Interface **10**(82): 20120939.

36. Cedervall, T., et al. (2012). „Food chain transport of nanoparticles affects behaviour and fat metabolism in fish.“ PLoS One **7**(2): e32254.; Hawthorne, J., et al. (2014). „Particle-size dependent accumulation and trophic transfer of cerium oxide through a terrestrial food chain.“ Environ Sci Technol **48**(22): 13102–13109; Lee, W. M. and Y. J. An (2015). „Evidence of three-level trophic transfer of quantum dots in an aquatic food chain by using bioimaging.“ Nanotoxicol **9**: 407–412; Bour, A., et al. (2015). „Toxicity of CeO_2 nanoparticles on a freshwater experimental trophic chain: A study in environmentally relevant conditions through the use of mesocosms.“ Nanotoxicol: 1–11.; Skjolding, L. M., et al. (2014). „Trophic transfer of differently functionalized zinc oxide nanoparticles from crustaceans (Daphnia magna) to zebrafish (Danio rerio).“ Aquat Toxicol **157**: 101–108.

37. Regulation (EC) 1907/2006.

38. Regulation (EC) 1272/2008.

39. Regulation (EU) 528/2012.

40. Regulation (EC) 1107/2009.

41. Directive 2001/83/EC and Regulation (EU) 2019/6.

42. Published on the same day on the Internet and on 20.10.2011 in EU OJ L 275, pp. 38–40 http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011H0696&from=EN

43. Rauscher, H., et al. (2014) „Towards a review of the EC Recommendation for a definition of the term „nanomaterial“ Part 1: Compilation of information concerning the experience with the definition, JRC Scientific and Policy Report, EUR 26567 EN.; Roebben, G. et al. (2014) „Towards a review of the EC Recommendation for a definition of the term „nanomaterial“ Part 2: Assessment of collected information concerning the experience with the definition, JRC Scientific and Policy Report, EUR 26744 EN.; Rauscher, H. et al. (2015) „Towards a review of the EC Recommendation for a definition of the term „nanomaterial“ Part 3: Scientific-technical evaluation of options to clarify the definition and to facilitate its implementation, JRC Scientific and Policy Report, EUR 27240 EN.

44. Rauscher, H., et al. (2019). „An overview of concepts and terms used in the European Commission's definition of nanomaterial“. JRC Science for Policy Report, EUR 29647 EN. https://ec.europa.eu/jrc/en/publication/overview-concepts-and-terms-used-european-commissions-definition-nanomaterial

45. Rauscher, H. et al. (2019). „Identification of nanomaterials through measurements“. JRC Science for Policy Report, EUR 29942 EN. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/identification-nanomaterials-through-measurements

46. see also: http://www.oecd.org/chemicalsafety/testing/oecd-guidelines-testing-chemicals-related-documents.htm

47. Regulation EC (No. 1223/2009), on cosmetic products; Regulation (EU) No 10/2011 on plastic materials and articles intended to come into contact with food; Regulation on the provision of food information to consumers as regards the definition of ‚engineered nanomaterials.' (EU (No.) 1363/2013).

48. *inter alia* within the EU H2020 projects Gov4Nano and NanoHarmony: https://www.gov4nano.eu/; https://nanoharmony.eu/; see also Table 2 on research projects and reports of UBA

49. http://www.oecd.org/chemicalsafety/testing/oecd-guidelines-testing-chemicals-related-documents.htm

50. An endpoint represents the key parameter to be determined in an investigation, e. g. acute aquatic toxicity or environmental degradation.

51. Hund-Rinke, K., et al. (2015). „Test strategy for assessing the risks of nanomaterials in the environment considering general regulatory procedures." Environmental Sciences Europe **27**(1).

52. Hildebrand H, et al. (2019). „Analysis of studies and research projects regarding the detection of nanomaterials in different environmental compartments and deduction of need for action regarding method development." UBA TEXTE 133/2019, https://cms.umweltbundesamt.de/publikationen/nanomaterials-environmental-compartments

53. Praetorius, A., et al. (2014). „The road to nowhere: equilibrium partition coefficients for nanoparticles." Environmental Science: Nano **1**(4): 317.

54. OECD Guidelines for the Testing of Chemicals: http://www.oecd.org/chemicalsafety/testing/oecdguidelinesforthetestingofchemicals.htm

55. see also: http://www.oecd.org/chemicalsafety/nanosafety/dossiers-and-endpoints-testing-programme-manufactured-nanomaterials.htm

56. OECD Environment Directorate (2014): Ecotoxicology and environmental fate of manufactured nanomaterials: test guidelines. Expert Meeting Report. Series on the Safety of Manufactured Nanomaterials No. 40 (ENV/JM/MONO(2014)1): http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/JM/MONO(2014)1&doclanguage=en

57. Petersen, E. J., et al. (2015). „Adapting OECD Aquatic Toxicity Tests for Use with Manufactured Nanomaterials: Key Issues and Consensus Recommendations." Environ Sci Technol **49**: 9532–9547.

58. OECD (2017). OECD Test Guideline on Dispersion Stability of Nanomaterials in Simulated Environmental Media (OECD TG No. 318); OECD (2020). OECD Guidance Document on Aquatic and Sediment Toxicological Testing of Nanomaterials (OECD GD No. 317); OECD (2020). OECD Guidance Document for the Testing of Dissolution and Dispersion Stability of Nanomaterials, and the Use of the Data for Further Environmental Testing and Assessment (OECD GD No. 318).

59. see also: http://www.oecd.org/chemicalsafety/testing/oecd-guidelines-testing-chemicals-related-documents.htm

60. OECD (2014). ENV/JM/MONO(2014)4 OECD Guidance on Grouping of Chemicals, Second Edition, Series on Testing & Assessment No.194.

61. ECHA (2008). ECHA Guidance on information requirements and chemical safety assessment, Chapter R.6: QSAR and grouping of chemicals http://echa.europa.eu/documents/10162/13632/information_requirements_r6_en.pdf

62. ECHA (2019). Guidance on information requirements and chemical safety assessment – Appendix R.6-1 for nanomaterials applicable to the Guidance on QSARs and Grouping of Chemicals. https://echa.europa.eu/documents/10162/23036412/appendix_r6_nanomaterials_en.pdf

63. A nanoform is considered as form of a substances which falls under the EU recommendation on the definition of a nanomaterial as published in October 2011.

64. Sellers, K. et al. (2015). „Grouping nanomaterials: A strategy towards grouping and read-across." RIVM Report 2015-0061.; Oomen, A. G. et al. (2015). „Grouping and Read-Across Approaches for Risk Assessment of Nanomaterials." Int J Env Res Public Health **12**: 13415–13434.

65. Schwirn K., Völker D. (2019). „Hazard grouping of nanomaterials for daphnia and algae toxicity: lessons learned from scientific projects for regulatory applicability." Environ Sci Eur **31**:48.

66. ClientEarth, CIEL, BUND (2012). High time to act on nanomaterials – A proposal for a nano patch for EU regulation: http://www.ciel.org/Publications/Nanopatch_EU_Nov2012.pdf

67. KemI 2013: Draft Proposal For a Regulation on Nanomaterials

68. UBA, BfR, BAuA (2013): Nanomaterials and REACH – Background Paper on the Position of German Competent Authorities: https://www.umweltbundesamt.de/publikationen/nanomaterials-reach

69. European Commission (2018). Commission Regulation (EU) 2018/1881 of 3 December 2018 amending Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) as regards Annexes I, III,VI, VII, VIII, IX, X, XI, and XII to address nanoforms of substances. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R1881

70. The obligation to update existing registration dossiers also arises from the Commission Implementing Regulation (EU) 2020/1435 on the duties placed on registrants to update their registrations under Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). https://eur-lex.europa.eu/eli/reg_impl/2020/1435/oj

71. see also: https://echa.europa.eu/de/guidance-documents/guidance-on-information-requirements-and-chemical-safety-assessment

72. European Commission (2020). Commission Regulation (EU) 2020/878 of 18 June 2020 amending Annex II to Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R0878&from=EN

73. https://www.echa.europa.eu/de/web/guest/information-on-chemicals/evaluation/community-rolling-action-plan/corap-table

74. Ministrère de l'Ecologie, du Dévelopment durable et de l'Ènergie, France, 2014. Éléments issus des déclarations des substances à l'état nanoparticulaire -Rapport d'etude 2014

75. EFSA (2014). Inventory of Nanotechnology applications in agricultural, feed and food sector (CFT/EFSA/FEED/2012/01). https://efsa.onlinelibrary.wiley.com/doi/abs/10.2903/sp.efsa.2014.EN-621

76. Gogos, A. et al. (2012). „Nanomaterials in plant protection and fertilization: current state, foreseen applications, and research priorities." J Agricult Food Chem **60**, 9781–9792.; Kah, M., Hofmann, T. (2014). „Nanopesticide research: current trends and future priorities." Environ Int **63**, 224–235.

77. http://www.biozid.info/deutsch/biozidverfahren/

78. EFSA (2014). Inventory of Nanotechnology applications in agricultural, feed and food sector (CFT/EFSA/FEED/2012/01). https://efsa.onlinelibrary.wiley.com/doi/abs/10.2903/sp.efsa.2014.EN-621

79. Written information of BVL (30 June 2020)

80. EFSA (2018). „Guidance on the risk assessment of the application of nanoscience and nanotechnologies in the food and feed chain: Part 1, human and animal health." EFSA Journal 2018; 16(7): 5327.

81. Next to their potential to be utilized in medicinal products, nanomaterials feature potential for application in medicinal devices. However, as medicinal devices are not subjected to environmental risk assessment, no separate analysis for nanomaterials in medical devices is performed here.

82. European Medicines Agency (2010). „1st EMA Workshop on Nanomedicines." London.http://www.ema.europa.eu/ema/index.jsp?curl=pages/news_and_events/events/2009/12/event_detail_000095.jsp&mid=WC0b01ac058004d5c3

83. Bleeker et al. (2015). „Assessing health & environmental risks of nanoparticles – Current state of affairs in policy, science and areas of application". RIVM Report 2014-0157.

84. Berkner, S., et al. (2015). „Nanopharmaceuticals – tiny challenges for the environmental risk assessment of pharmaceuticals." Environ Toxicol Chem **35**(4): 780–787.

85. Hermann, A. et al. (2013). „Assessment of impacts of a European register of products containing nanomaterials." http://www.umweltbundesamt.de/publikationen/assessment-of-impacts-of-a-european-register-of

86. European Medicines Agency (2019). „Advice implementing measures under Article 146(2) of Regulation (EU) 2019/6 on veterinary medicinal products – Scientific recommendation on the revision of Annex II to Regulation (EU) 2019/6 on veterinary medicinal products." https://ec.europa.eu/food/sites/food/files/animals/docs/ah_vet-med_imp-reg-2019-06_ema-advice_art-146-2.pdf

87. http://www.beuc.eu/safety/nanotechnology, http://www.bund.net/nanodatenbank/

88. http://www.nanopartikel.info/en/nanoinfo/knowledge-base

89. https://www.r-nano.fr/, http://www.health.belgium.be/en/environment/chemical-substances/nanomaterials/register, http://eng.mst.dk/topics/chemicals/nanomaterials/the-danish-nanoproduct-register/, https://www.environmentagency.no/areas-of-activity/product-register/, https://www.kemi.se/en/products-register/products-obliged-to-be-reported/compulsory-declaration-for-nanomaterial

90. UBA (2012). „Concept for a European Register of Products Containing Nanomaterials." http://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/information_concept_nanoregister_npr_e_0.pdf

91. Hermann, A. et al. (2013). „Assessment of Impact of a European Register of Products containing Nanomaterials." http://www.umweltbundesamt.de/publikationen/assessment-of-impacts-of-a-european-register-of

92. see also: https://euon.echa.europa.eu/

93. UBA (2009). „Backgroundpaper: Nanotechnology for human and environment." http://www.umweltbundesamt.de/publikationen/nanotechnology-for-humans-environment

94. https://www.umweltbundesamt.de/publikationen/nanomaterials-other-advanced-materials-application

95. http://www.umweltbundesamt.de/en/topics/chemicals/nanotechnology

96. The Strategic Approach to International Chemical Management (SAICM) is an under international low, non-binding, overarching, political framework within the environmental programme of the United Nations (UNEP) for the international chemicals management.

97. SAICM (2015). SAICM/ICCM.4/9. Emerging policy issues and other issues of concern. http://www.saicm.org/Portals/12/documents/meetings/ICCM4/doc/k1502183%20SAICM-ICCM4-9-e.pdf

Annex

Table 1

National and international cooperation and participation in panels/boards since 2009

Internat. and nat. cooperation and participation in panels	Brief description
Joint Research Strategy of German Governmental Research Institutions (together with BAuA, BfR, BAM and PTB): „Nanotechnology – Risks related to Nanomaterials for Humans and the Environment“ (since 2007)	Review regarding the research of German supreme federal authorities on nanosafety and alignment of future research within the focus of the joint research strategy. Emphasis is given on scientific issues supporting regulation and risk assessment of nanomaterials to protect humans and environment.
The Nano Dialogue of the Federal Government: Participation in issue groups to support the work of the NanoKommission (until 2011) and in expert dialogues (since 2011) (with representatives from NGOs, industry, science and authorities)	Active participation in different issue groups of the NanoKommission, as well as in expert dialogues on different topics (Assessment, regulation, traceability, sustainability, research, nanomedicine, aquatic environment, waste and disposal, advanced materials)
OECD Working Party on Manufactured Nanomaterials (WPMN) (since 2006)	„Sponsorship Programme“ with main responsibility for the dossier on TiO_2 („lead sponsor“), partial responsibility for the dossier on Ag („co sponsor“) and support of dossiers for four additional nanomaterials. Steering Group „Testing and Assessment“: Assessment of data regarding environment, development of OECD test guidelines and guidance documents specific for nanomaterials. Steering Group „Environmentally Sustainable Use of Manufactured Nanomaterials“: knowledge building about life cycle aspects, development of instruments and guidance manual towards integration of risk assessment into life cycle assessment of nano-enabled applications.
OECD Working Party on Resource Productivity and Waste (WPRPW)	Currently, the WPRPW deals with four projects on nanomaterial-containing waste. UBA is leading a report regarding waste incineration. In this report, information on the incineration of waste containing nanoscale TiO_2 are processed which were deduced from a project dealing with the disposal of nanomaterial-containing waste in waste incineration plants.
Nanomaterial Expert Group (NMEG) of the ECHA (since 2012)	The NMEG consists of representatives of EU MS, ECHA and observers from industry and NGO. Task of the NMEG is the discussion of topics relevant for the regulation of nanomaterials in order to support ECHA in their tasks (e. g. development of specific guidances) by giving expert advice. Important aspects are the physical-chemical characterization of nanomaterials and the development of analogy concepts for grouping and read across specifically for nanomaterials.
Competence Authority Sub Group on Nanomaterials (CASG Nano)	In the CASG Nano, experts discuss the adaptation of the European chemical regulation REACH to nanomaterials, as well as additional aspects of regulation of nanomaterials, i. e. the EU definition and transparency measures for products containing nanomaterials. On behalf of the Federal Ministry for the Environment, Nature Conversation, Building and Nuclear Safety, UBA supports the German representative by giving expert advice.
Strategic Approach to International Chemicals Management (SAICM)	At the 4thInternational Conference on Chemicals Management of SAICM (autumn 2015), it was decided to continue activities regarding the emerging policy issue „nanotechnology and manufactured nanomaterials“. UBA supports by commenting related documents of SAICM.
Group assessing already registered Nanomaterials (GAARN) (January 2012–October 2013)	GAARN was constituted by the European Commission (GD ENV) as informal advisory group with the task to find consensus regarding an adequate assessment of nanomaterials in the framework of the REACH regulation and thus, improve trust and mutual understanding between concerned parties.
REACH Implementation Project on Nanomaterials (RIPoN) 1 (October 2009 – March 2011)	Technical as well as scientific advice regarding substance identity of nanomaterials under the REACH regulation

Table 2

Research projects and reports regarding nanotechnology on behalf of the Umweltbundesamt (2009–today)

Research Project/Report	Duration	Short description
Analysis and Strategic Management of Nanoproducts with Regard to their Sustainability Potential – Nano-Sustainability Check	2009–2011	Am of this study was the development of a „Nano-Sustainability Check“ to examine the sustainability of products and applications involving nanomaterials with respect to their potential environmental benefits but also potential threats to the environment. The most important feature in this context is an evaluation grid which can be used to compare benefits and risks of a nano-enabled product to an existing reference product that has been manufactured without the use of nanomaterials. The results of this study allow to develop recommendations for a strategic optimization of the investigated applications to maximize the potential strengths and opportunities with regard to sustainability while minimizing the potential negative effects. The methodical approach was described by two case studies (surface coating of glass, concrete catalyst). http://www.umweltbundesamt.de/publikationen/analysis-strategic-management-of-nanoproducts
Investigation of widely used nanomaterials (TiO2, Ag) and gold nanoparticles in standardized ecotoxicological tests	2009–2012	Aim of this study was to collect basic data on ecotoxicology of selected nanomaterials. For this aim, standardized OECD test guidelines were used which were also checked for their applicability to determine the ecotoxic effect of nanomaterials. http://www.umweltbundesamt.de/publikationen/investigation-of-widely-used-nanomaterials-tio2-ag
Fate and behavior of TiO2 nanomaterials in the environment, influenced by their shape, size and surface area	2009–2011	This study investigated the behavior and fate of different nanoscale TiO_2 in different environmental matrices. Amongst other tests, a simulation of the passage through a sewage treatment plant was performed. In addition, OECD test guidelines applied in this study were checked for their applicability for investigating nanomaterials. http://www.umweltbundesamt.de/publikationen/fate-behaviour-of-tio2-nanomaterials-in-environment
Investigation of two widely used nanomaterials (TiO2, Ag) for ecotoxicological long-term effects Adaption of test guidelines	2009–2012	In this study standardized OECD test methods were used to investigate potential ecotoxic long-term effects of nanomaterials. Amongst other tests, an Early Life Stage Test with fish was performed with nanosilver. In addition, OECD test guidelines applied in this study were checked for their applicability for investigating nanomaterials. http://www.umweltbundesamt.de/publikationen/investigation-of-two-widely-used-nanomaterials-tio2
Environmental hazard of selected TiO2 nanomaterials under consideration of relevant exposure scenarios	2010–2013	In this study specific ecotoxicological scenarios with selected TiO_2 nanomaterials were investigated. Using different standardized OECD test methods, mixture experiments with nano-TiO2 and an organic contaminant as well as toxicity tests under solar radiation were performed. http://www.umweltbundesamt.de/publikationen/environmental-hazard-of-selected-tio2-nanomaterials
Mobility, fate and behavior of TiO2 nanomaterials in different environmental media	2010–2012	This study dealt with the environmental fate of TiO_2 nanomaterials. Different aspects were investigated, i. e. the stability of different coatings as well as the mutual influence of nanomaterials and pollutants on fate and behaviour in the environment. http://www.umweltbundesamt.de/publikationen/mobility-fate-behavior-of-tio2-nanomaterials-in

Research Project/Report	Duration	Short description
Carcinogenicity and Mutagenicity of Nanoparticles – Assessment of Current Knowledge as Basis for Regulation	2010–2012	In this research project, long-term studies with rodents and different nanomaterials were surveyed to identify rele-vant indicators of toxicity including possible precursors of carcinogenicity. Due to the heterogeneous characteristics of the materials and the different study types, a structured and systematic data analysis was performed by means of a relational database. More than 100 studies on inhalation and instillation with nanomaterials like Carbon Black, SiO2, metals, metal oxides, and carbon nanotubes were analysed. Effects like neutrophil number, total protein and LDH con-tent in the bronchioalveolar lavage fluid (BALF) proved to be frequently measured and to be sensitive indicators of toxicity of all particles/fibers investigated. In addition, infiltration of inflammatory cells in the lung and increased lung weights were often observed. http://www.umweltbundesamt.de/publikationen/carcinogenicity-mutagenicity-of-nanoparticles
Toxicology of Nanomaterials, modes of action and carcinogenicity – kinetics of CNT after short term inhalation	2010–2012	Rats were exposed to carbon nanotubes (MWCNTs) in a short-term inhalation study. The objective of the study was to investigate the uptake, distribution, and excretion of MWCNTs. In lung lavage inflammatory reactions were observed 1 day after exposure but not 28 days after exposure. Individual MWCNTs were detected in liver, kidneys and in the agarose cast of the pleural cavity using a high resolution light microscope. Final report (available in German with English abstract): http://www.umweltbundesamt.de/publikationen/toxikologie-von-nanomaterialien-wirkmechanismen
Evaluation of chronic toxicity/carcinogenicity of nanomaterials using nano-CeO2	2012–2018	To fully reveal relevant health hazards of selected nanoparticles BASF Experimental Toxicology performed a long-term inhalation study under the auspices of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and in collaboration with the higher federal authorities BAuA, BfR und UBA. This whole-body inhalation study was performed according to OECD test guideline no. 453 with several protocol extensions. https://www.bmu.de/themen/forschung-foerderung/forschung/forschungs-und-entwicklungsberichte/details/bewertung-der-chronischen-toxizitaetkanzerogenitaet-ausgewaehlter-nanomaterialien-und-histopatologisch/
Investigation of the influence of selected nanoenabled products on the raw material and energy demands	2011–2013	The applications described in the study show that, in general, nanotechnological innovations can save significant amounts of resources and energy. However, these potentials depend at least partially on boundary conditions that still have to become reality in future. With regard to the effects of nano-enabled products on the consumption rate of raw materials and energy, as well as for the determination of relevant rebound effects, the results of the study show that the analysis of the entire life cycle of an application is an absolute prerequisite for obtaining reliable results. Final report (available in German with English abstract): http://www.umweltbundesamt.de/publikationen/untersuchung-der-auswirkungen-ausgewaehlter

Research Project/Report	Duration	Short description
Legal questions regarding the application of the substance definition to nanomaterials within the framework of the REACH Regulation	2011–2012	Aim of this study was to investigate how current regulations like REACH and CLP need to be adapted in order to cover nanomaterials appropriately. It was examined if it is therefore necessary to amend the definition of the term substance in Art. 3 REACH. Final report (available in German with English abstract): http://www.bmub.bund.de/fileadmin/Daten_BMU/Pools/Forschungsdatenbank/fkz_3711_65_434_nanomaterialien_reach_bf.pdf
Assessment of Impacts of a European Register of Products Containing Nanomaterials	2012–2013	Aim of this study was to identify and analyze the impacts of a „Concept of a European Register of Products Containing Nanomaterials“ which was developed by UBA. Therefore, sectors and companies affected by such a register were identified and a number of products were estimated. Based on these data, the administrative costs of concerned companies and competent authorities were quantified. Finally, the impact of such a register on innovation and competition, as well as the benefits for public authorities, consumers and notifiers were described. http://www.umweltbundesamt.de/publikationen/assessment-of-impacts-of-a-european-register-of
Integrative Test Strategy for the Environmental Assessment of Nanomaterials	2012–2014	Objective of this study was to develop a tiered strategy for the investigation of ecotoxicity and environmental fate, that allows both -the considerations of conventional test requirements and alternative aspects, specific for nanomaterials. http://www.umweltbundesamt.de/publikationen/integrative-test-strategy-for-the-environmental
Survey on possible Environmental Exposure of Disposal of Waste Containing Nanomaterials	2012–2015	Aim of the study was the investigation of the behaviour of nanomaterials during the incineration using nanoscale TiO_2. In order to optimize the application technique into the waste as well as the measurement technique, nanomaterials were incinerated in a small scale incineration plant. In addition, experiments were performed in a real existing waste incineration plant and a sewage sludge incineration plant. Final report (available in German with English abstract): https://www.umweltbundesamt.de/publikationen/untersu-chung-moeglicher-umweltauswirkungen-bei-der
Clarification of Methodological Questions regarding the Investigation of Nanomaterials in the Environment – Development of a Decision Support Tool for the Investigation of Nanomaterials Environmental Behavior of Nanomaterials based on Dispersion Stability and Dissolution in relation to various Environmental Parameters	2013–2016	In this study, a draft for a new OECD test guideline dealing with the examination of agglomeration and agglomeration behavior of nanomaterials in the aquatic environment was developed. In addition, a first proposal for a guidance document was compiled, dealing with a tiered approach for the investigation of dissolution and agglomeration of nanomaterials, which can be used for decision-making on further tests on environmental behavior of nanomaterials. https://www.umweltbundesamt.de/publikationen/clarification-of-methodical-questions-regarding-the OECD Test Guideline 318: https://www.oecd-ilibrary.org/environment/test-no-318-dispersion-stability-of-nanomaterials-in-simulated-environmental-media_9789264284142-en
Considerations about the relationship of nanomaterial's physical-chemical properties and aquatic toxicity for the purpose of grouping	2014–2017	The study aimed to correlate physical-chemical properties with ecotoxic effects. For this objective, selected nanomaterials with defined properties were investigated for their short-term toxicity using standardized OECD methods. https://www.umweltbundesamt.de/publikationen/considerations-about-the-relationship-of

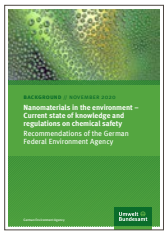
Research Project/Report	Duration	Short description
Development of a method to determine the bioaccumulation of manufactured nanomaterials in filtering organisms (*Bivalvia*)	2016–2019	In this project a method was developed which allows to investigate the bioaccumulation of nanomaterials in freshwater mussels. The new method was examined using nanomaterials of different chemical nature unter consideration of neccessary adaptations for investigating nanomaterials in filtering organisms. https://www.umweltbundesamt.de/publikationen/development-of-a-method-to-determine-the
Investigations on the possible release of nanoparticles during the deposition and soil-related application of mineral waste	2016–2019	In 2015 a research project was completed („Survey on possible environmental exposure of disposal of waste containing nanomaterials", see above) where it was shown that in a waste incineration plant during a state of the art combustion process of nanomaterials containing waste no higher emissions of nanomaterials in the purified exhaust gas were detected. Nanomaterials were mainly found in the solid residues of the combustion process (ashes and slags). Therefore, the focus of this project was to analyze to what extent nanoparticles could be released in the environment during recovery and disposal of combustion residues. Final report (available in German with English abstract): https://www.umweltbundesamt.de/publikationen/untersuchungen-zur-moeglichen-freisetzung-von
Development of an OECD Test Guideline on nanomaterial size and size distribution	2017–2020	The project aims to develop a harmonised test protocol (OECD test guideline) for a valid and reproducible determination of particle size und size distribution which is one of the moste relevant physical-chemical properties. The project will focus on particulate and fibrous nanomaterials.
Development of a Guidance Document for the interpretation of data on dissolution rate and dispersion stability of nanomaterials for environmental risk assessment	2017–2020	In this project a guidance document was developed which provides guidance and recommendations for the use of the test guideline on dispersion stability of nanomaterials and existing guidance for substances to determine solubility and dissolution rate for nanomaterials. Furthermore, the guidance addresses the interpretation of data coming from these guideline and guidance with respect to the conduction of follow-up testing on environmental fate (and effects) of nanomaterials in the environment. In April 2020, the draft of the guidance was approved as new OECD guidance document by the OECD test guideline program (OECD WNT). OECD Guidance Document 318: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2020)9&doclanguage=en
Analysis of studies and research projects regarding the detection of nanomaterials in different environmental compartments and deduction of need for action regarding method development	2018–2019	Content of the survey is the analyses of recent scientific studies, research projects and relevant activities of standardisation boards regarding the availability and development of suitable detection and analysis methods for nanomaterials in the different environmental compartments. Based on this analysis, the survey will provide a gap analysis and deduce short term, mid term and long term actions required for method development and standardisation. https://cms.umweltbundesamt.de/publikationen/nanomaterials-environmental-compartments
Development of a bioaccumulation test with *Hyalella azteca*	2018–2020	The project accompanies the development of a potentially new OECD test guideline for the determination of bioaccumulation of substances in *Hyalella azteca*. It will investigate the applicability, resilience, and limitation of this non-vertebrate test method for highly lipophilic organic substances and nanomaterials.

Research Project/Report	Duration	Short description
Advanced materials – Thematic conferences: Assessment of needs to act on chemical safety	2019–2021	The project will conduct a survey on advanced materials on the European market and their meaning for risk assessment in the framework of chemical legislation. For this, relevant advanced materials and their applications will be identified and described according to their chemical composition and structure, their behavior and potential hazardous effects on human and environment. In a series of topic conferences the results of the survey will be discussed with stakeholders (i. e. regulatory agencies, science, industry, NGO) and recommendations for action for ensuring and improving safety of human and the environment will be deduced. https://www.umweltbundesamt.de/publikationen/advanced-materials-overview-of-the-field-screening
Standardisation of methods regarding fate and behaviour of nanomaterials in environmental media – solubility and dissolution rate	2019–2022	The objective of the project is to develop a working protocol which will include measurements under static and dynamic conditions in order to determine solubility and dissolution rate of nanomaterials under environmental relevant conditions. It is intended to submit the working protocol at OECD level to pursue the adoption as new OECD test guideline.

Table 3

Participation and partnership in national and international externally funded research projects

Title of project	Duration	Funding source	Topic
UMSICHT	2010–2013	BMBF (Federal Ministry of Education and Research)	Assessment of the environmental hazards of silver nanomaterials
DENANA	2014–2017	BMBF	Design criteria for sustainable nanomaterials
NanoGRAVUR	2015–2018	BMBF	Nanostructured materials – Grouping regarding worker, consumer, and environment safety and risk mitigation
NanoMobil (UBA acts as associated partner)	2014–2017	BMBF	Synthetic Silver Nanoparticles in the system Soil-Groundwater – mobility, effects on cohabitation and interaction between hydro, pedo- and biosphere
NanoUmwelt (UBA acts as associated partner)	2014–2017	BMBF	Risk analysis of engineered nanomaterials in the environment: identification, quantification and analysis of the human- and ecotoxic effects
SOILMOBILE (INTERNANO)	2015–2018	DFG (German Research Association)	Mobility, aging and functioning of engineered inorganic nanoparticles at the aquatic-terrestrial interface
ProSafe	2015–2017	EU Horizon 2020	Promoting the safe implementation of nanomaterials
NanoFase (UBA participates in the advisory board)	2015–2019	EU Horizon 2020	Nanomaterial fate and specification in the environment
NanoHarmony (UBA participates in the advisory board)	2020–2023	EU Horizon 2020	Towards harmonised test methods for nanomaterials



▸ **Our brochures to download**
Short link: bit.ly/2dowYYI

www.facebook.com/umweltbundesamt.de
www.twitter.com/umweltbundesamt
www.youtube.com/user/umweltbundesamt
www.instagram.com/umweltbundesamt/