

NanoDialogue
of the German Government

**Identification and communication of risks from
nanomaterials – simply explained**

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1 Introduction

Since 2006, companies, authorities, civil society organisations and academia have discussed various aspects of the sustainable use of nanomaterials in the frame of the German NanoDialogue. Since the Dialogue's beginning, stakeholders confirm that the general public is hardly aware of how the properties of nanomaterials are identified and communicated. In addition, they would normally not understand the difference between the hazardous properties that could damage the environment or human health and the risks that could occur from the use of nanomaterials. However, this difference would be very important to assess whether or not the use of a particular nanomaterial is "problematic" from a societal point of view.

Nanomaterials are specific chemicals and are regulated by the same legislation as any other chemical. However, many have particular properties which may require a different implementation of this legislation.

This report briefly and simply explains:

- what chemicals and nanomaterials are;
- how their hazardous properties are identified and which particularities exist for nanomaterials and
- how it is assessed, which risks from the use of chemicals, including nanomaterials, could occur.

For the sake of understandability and conciseness, the report sometimes shortens and simplifies facts and conditions and abstains from explaining exemptions and details that are not important in the current context. In the last chapter, links are compiled to help the readers gather further information and knowledge.

2 What are chemicals and what are nanomaterials?

The term "**chemicals**" addresses substances and mixtures produced from them:¹

- **Substances** are chemically clearly defined. They may occur naturally, e.g. oxygen, iron, table salt and citric acid and/or may be intentionally produced in biological or chemical processes, such as turpentine, PVC² or nylon. Prior to placing on the market, all substances in the EU have to be registered at the European Chemicals Agency, which assigns a so called EC number to each.

¹ To avoid misunderstandings, the terms „substance“ and „mixture“ are used as defined in Art. 3 of the EU chemicals regulation REACH ((EC) No. 1907/2006).

² Polyvinyl chloride, a plastic.

- **Mixtures** are chemical products and are produced by “intentionally” mixing different substances. Some examples of mixtures are cleaning agents, lacquers, shoe polish and cosmetics.

Substances and mixtures can occur in different physical states (aggregate state):

- solid (substance: table salt; mixture: washing powder),
- liquid (substance: acetic acid; mixture: dishwashing agent) or
- gaseous (substance: helium; mixture: asthma spray).

Nanomaterials are substances in a solid state and measure between 1 and 100 nanometres (nm) in at least one dimension, i.e. they are more than 1 and less than 100 nm long, thick and/or wide. This is also referred to as “nanoscale”. Nanomaterials may take on the form of spheres (3 dimensions at nanoscale), fibres (2 dimensions at nanoscale) or plates (1 dimension at nanoscale). One nanometre is the millionth part of a millimetre, i.e. 0.000001 mm. 1 nm is 1,000 times thinner than a hair; DNA has a diameter of app. 1 nm and viruses measure between 30 and 50 nm.

Nanomaterials are manufactured because they have technically needed novel or improved properties compared to the existing substances, such as:

- Due to their small size, nanomaterials have a large surface area compared to their volume. Therefore, they often react quicker and more strongly than other chemicals (increased reactivity).
- As they are particles, nanomaterials frequently do not dissolve in water but adhere to surfaces.
- Certain nanomaterials are particularly good or bad conductors of temperature or electricity or are used for optical applications, such as in light emitting diodes (LED).
- Some nanomaterials are produced and used because they are very strong and light-weight at the same time.

In conclusion, nanomaterials are a sub-group of substances that are solid particles at nanoscale. They are also called “nano forms”. Consequently, it is possible that one “species” of a substance with a defined composition exists as a “large”, so called macroscale form and – as nanoparticles may have different forms and sizes – as several nano forms. The chemical name of the substance would be the same in all cases. Figure 1 shows this systematics.

CHEMICAL SUBSTANCES AND NANOMATERIALS

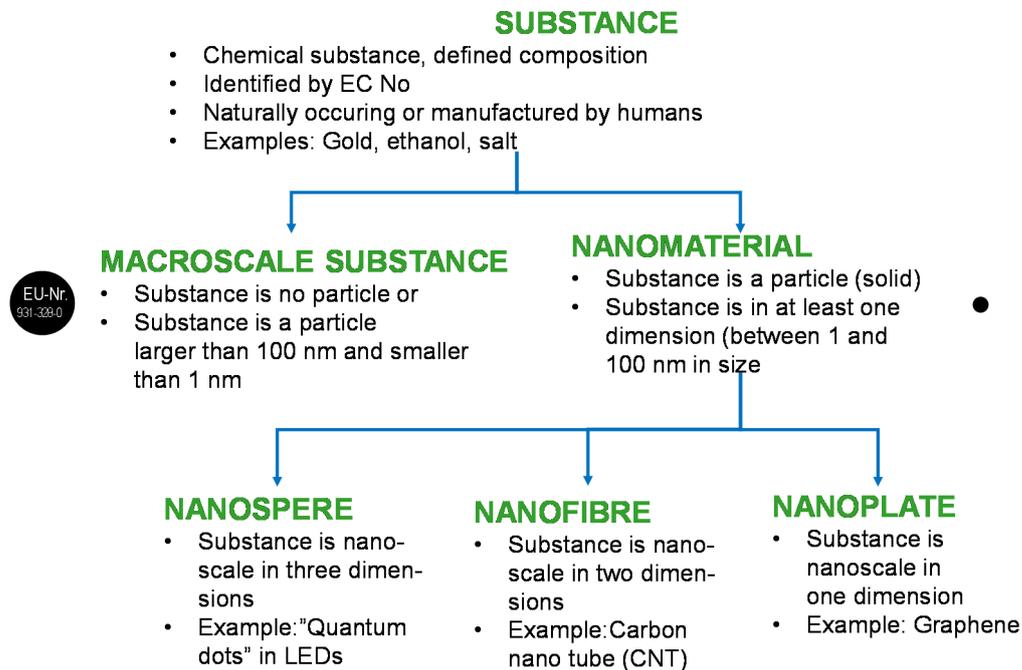


Figure 1: Substances and nanomaterials (Source: Oekopol GmbH)

An example of a substance that occurs in many forms is carbon:

- Forms in "macroscale" are e.g. graphite (pencil lead) or diamond.
- It exists at nanoscale as spheres ("bucky balls"), flakes (graphene) and tubes (carbon nano tubes = CNT).

In our daily lives we handle **articles** rather than substances and mixtures. Articles differ from chemicals in that their solid form is more important than their chemical composition. If we need a table, it is important that we have a large, horizontal surface and it does not matter if it is made of plastics, wood or metal.

Articles are not chemicals but may contain them: clothes are coloured with dyes, cars are protected and decorated by lacquers etc. Chemicals may be on the surface of articles or integrated in the materials they are made of. For example phthalates are included in certain plastics in order to make them soft and flexible. The plastics should maintain this property for a long time and therefore phthalates are comparatively firmly integrated in the materials. Nevertheless they can (slowly but continuously) be released from the plastics and it loses its flexibility.³

³ This can be observed with garden furniture: when it is new, it is shiny and flexible. Softeners and pigments are eventually destroyed by sunlight or washed off by rainwater. As time passes by, the furniture bleaches and becomes brittle.

3 What makes chemicals “problematic“?

Unfortunately, it is not easy to answer this question because several issues need to be considered. In the context of chemicals, “problematic” means damaging human health or the environment. To assess if a substance could cause harm, two aspects are important: the **hazards** of a substance and if humans or the environment may come into contact with it. The second aspect is called **exposure**. The combination of hazard and exposure determines the **risk** of damage from the use of a substance. In the following, this is explained in more detail.

3.1 What is a risk?

The **risk** – or in colloquial language if a substance is “problematic” - expresses the likelihood that a substance damages the environment or human health. A metaphor to illustrate the term “risk” is a **lion in the zoo**: there is no doubt that a lion could hurt humans (hazard), but only if he can escape from the cage (exposure). As the likelihood of a lion escaping from its cage is comparatively low, the risk of being hurt by a lion in the zoo is also low. Figure 2 reflects this relation: at the left a chemical is enclosed in a bottle, at the right it is released and harms the person (dizziness).



Figure 2: Hazard and exposure
(Source: Oekopol GmbH, DHI and Helle Simon Elbro)

The risk of being hurt by a guinea pig is also low but not (only) because it does not escape from its cage but also (and more so) because it is small and cannot really harm humans. A similar relation exists regarding chemical substances: they may cause damage only, when they are hazardous and “free”. The next chapters explain “hazard” and “exposure” further and how they are determined.

3.2 What does hazard mean?

3.2.1 What are adverse effects?

Chemicals may harm humans and the environment by changing biological structures or processes. Some substances can destroy cells or their components (e.g. DNA, proteins), others can adhere to cellular structures or imitate hormones and thereby

disturb natural steering mechanisms. These negative impacts are also called “adverse effects” and are caused by (eco-)toxic⁴ properties. Substances may also have physical-chemical properties that could cause damage, such as explosivity or flammability but this report only refers to (eco-)toxic effects.

Approximately 50 years ago, a system⁵ was developed at EU level to ensure chemical hazards are identified and described in the same way, which is still in use (with some modifications). According to this system, adverse effects are differentiated into so called “hazard classes” of which the most important and most frequently applied ones are:

- **Toxicity**: symptoms typical for intoxication occur; frequently the harm is reversible; example: ethanol.
- **Corrosivity/Irritation**: skin, eyes or the respiratory tract are irreversibly damaged or reversibly irritated (healing is possible); example: acetic acid.
- **Sensitisation**: causing allergic reactions; example: fragrances and nickel.
- **Systemic Target Organ Toxicity**: one or several organs, such as the liver or kidneys are damaged, frequently irreversibly; example: tetrachloromethane⁶.
- **Carcinogenicity**: cancer may be initiated or its growth accelerated; example: benzene⁷.
- **Mutagenicity**: the DNA is changed/mutated; mutations may be reversed by the cellular “repair system”; example: nitrosamines⁸.
- **Reproductive Toxicity**: two types of effects are distinguished:
 - loss of fertility; e.g. polychlorinated biphenyls (PCB)⁹ and the risk that
 - the embryo is damaged, malformed or dies; e.g. alcohol.
- **Toxic to Aquatic Organisms**: algae or aquatic animals are killed or impaired in their vitality; e.g. acetone.

The above hazard classes have sub-categories, which either differ by the potency of the effect (e.g. lethal, toxic and harmful) or by the reliability of data indicating the effect (e.g. “may cause an effect” vs “is suspected of causing an effect”).

⁴ Toxic or ecotoxic effect.

⁵ EU Directive on hazardous substances (DIR 67/548/EEC). Since 2008, it was taken over to a new EU regulation ((EC) No. 1272/2008), which aligns the classification and labelling rules with a globally harmonised approach.

⁶ Tetrachloromethane was used for chemical cleaning. Due to its organ damaging effects it is prohibited nowadays.

⁷ Benzene is contained in fuels. Petrol stations are equipped with special ventilation to protect humans from inhaling benzene while fuelling their cars.

⁸ Nitrosamines may form, among others, when certain foods are heated. E.g. the potential content of nitrosamines in french fries is frequently discussed in the media. Nitrosamines may adhere to parts of the DNA and thereby change it.

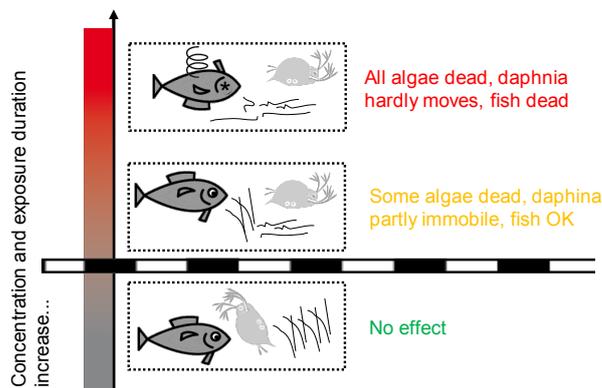
⁹ PCBs were used in various applications because of their persistence, in particular in transformers. Although their production and use was prohibited decades ago, they are still found in the environment and in humans, e.g. in breast milk.

According to current knowledge, **nanomaterials do not cause any adverse effects** that are not also observed at “macroscale”. Consequently, the hazard classes are also applicable to nanomaterials.

3.2.2 How are adverse effects identified?

A substance’s hazards are caused by its **hazardous properties** and these are identified via testing. How tests are to be conducted by laboratories is defined in test

TESTING TO IDENTIFY EFFECTS



guidelines which are developed in a common process among industry, authorities and science in the Organisation for Economic Cooperation and Development (OECD). If tests are conducted according to the test guidelines, the results are comparable and regarded as “reliable” across the globe. This means that tests only need to be done once for each substance and unnecessary suffering of animals can be avoided.

Figure 3: Assessment of substance impacts on the environment (Source: Oekopol GmbH, DHI and Helle Simon Elbro)

Organisms such as bacteria, algae, fish or rats or only parts of organisms, e.g. cells or skin models are used in the tests. They are exposed to the test substance (food, dermal contact or inhalation). Then it is observed if and how the health or vitality of (the parts of) the organisms change. Normally, several concentrations are tested to see, how effects change with increasing doses. Based on these observations it is concluded how the substance could impact on humans or the environment (c.f. Chapter 3.2.3).

Sometimes, the hazardous properties of a substance may also be identified without testing, e.g. by using computer models or comparing structure and properties of similar substances, among others.

To identify their hazardous properties, **the same tests are used for nanomaterials** as are used for substances at “macroscale”. However, some of the test guidelines were and are adapted to the specificities of nanomaterials, such as their increased reactivity and very low water solubility.

3.2.3 How are the test results evaluated and communicated?

As the significance of the test results are not understandable for most people, legislation includes rules for their interpretation. It is legally defined (c.f. footnote 5):

- which results trigger which hazard class and
- how information on chemical hazards must be communicated.

Figure 4 shows the steps for classification and the subsequent labelling.

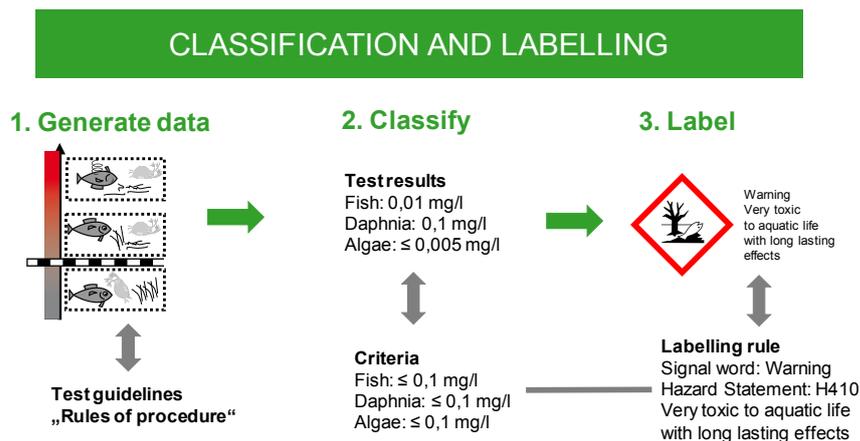


Figure 4: Steps of classification and labelling (Source: Oekopol GmbH)

Assigning hazard classes to a substance is called **classification**. It involves comparing test results with the legally defined criteria of a hazard class. If a substance fulfils a criterion¹⁰, it is classified in that hazard class. If a substance does not fulfil any criterion it is not classified (i.e. not hazardous) and the next steps are not necessary.

A certain classification is linked to elements of a prescribed communication of the hazardousness. If two substances have the same hazardous properties, the communicated (and standardised) information must also be the same. This information is included on the packaging of consumer products.

Chemicals hazard communication consists of three elements: a **pictogram**, i.e. a little figure, a **signal word**, which informs about the severity of the effect and a **hazard statement**, which describes the type of adverse effect. There are less pictograms and signal words than hazard statements, i.e. one pictogram/signal word is used for several effects. In contrast, each hazard statement is unambiguously linked to a hazard category. The classification and labelling can be regarded as a “translation” of test results to a standardised language on hazardous properties.

¹⁰ For example, a substance is considered “corrosive to the skin” if at the latest 4 hours after exposure the skin of at least three test animals is destroyed until a certain depth of the dermis.

The process and rules of **classification and labelling apply to nanomaterials** just as they do to substances at “macroscale”. As nanomaterials have a defined form and size, their hazards may differ from those of “macroscale” substances with identical composition. Therefore, they must be classified and labelled individually.

3.3 How are humans and the environment exposed to chemicals?

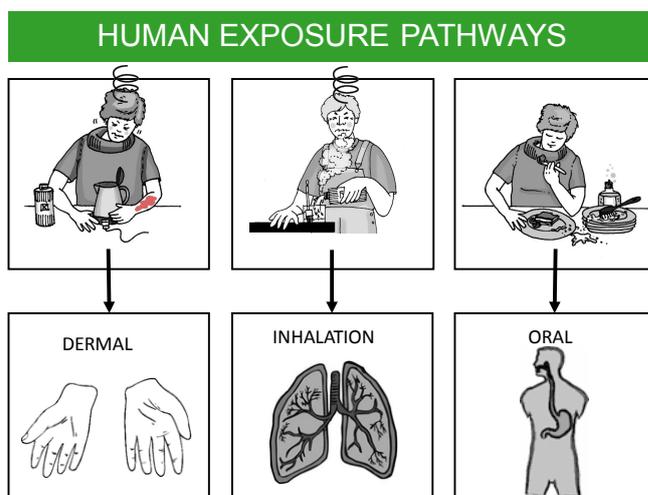
Everyone knows the saying by the physician Paracelsus “the dose makes the poison”, which illustrates that the amount taken up frequently co-determines the degree of damage. The “dose” is characterised by the **exposure level** (how much – concentration/amount), the **exposure duration** (how long – long/short) and the **exposure frequency** (how often – single/repeated exposure).

The effects from different doses of alcohol are commonly known: little amounts of alcohol hardly cause any observable effect, whereas larger amounts may e.g. limit the perception and the ability to move. Consuming very large amounts (over a short time period) usually causes an acute intoxication. The regular consumption of alcohol, even at small amounts may damage the liver and nervous system over a longer time period. During pregnancy it may damage the unborn child. These examples show that the ingested amount and the duration of exposure and sometimes even the time (pregnancy) of consumption may influence the effect. In the environment, alcohol in low concentrations/amounts can be regarded as “food” for microorganisms. However, high concentrations have a disinfecting effect, hence kill microorganisms.

Dose-effect relationships exist for substances at macroscale and nanoscale.

3.4 How do chemicals enter the body?

Substances can enter the human body in three ways, which are called exposure



pathways: via food and drink (oral), from air (inhalative) and through the skin (dermal). They are illustrated in Figure 5.

Lacquers often contain solvents, which can be smelled and are inhaled when the tin is opened. In addition, lacquer (including the solvent) may spill onto the skin and hence cause a dermal exposure.

Figure 5: Human exposure pathways (Source: Oekopol GmbH, DHI and Helle Simon Elbro)

Adverse effects may be dizziness and nausea (inhalation) and dry skin. It is obvious that the exposure pathways influence the effect of the chemical.

In the environment, the exposure pathways air, water and soil as well as the animals (biota) are also called compartments. Chemicals are distributed between these compartments over time and may also accumulate in the food chain. This is the cause of high heavy metals concentrations in fish.

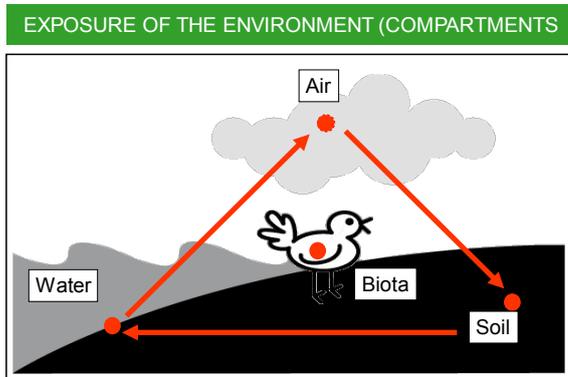


Figure 6: Exposure pathways of the environment (Source: Oekopol GmbH, DHI and Helle Simon Elbro)

There are some particularities to be considered in exposure assessments of nano-materials: some nanomaterials may cross physiological barriers (e.g. the blood-brain barrier), through which macroscale substances do not pass. Some may be transported quicker or differently and, for example reach the brain via the olfactory nerve. In addition, currently there is little information available on how nanomaterials are metabolised and/or excreted from the body. All these factors (also) influence the exposure level and duration.

As they are particles and therefore hardly soluble in water, nanomaterials partition differently in the environment than “macroscale” substances (they rather accumulate in soil and air). In addition, it is frequently unclear if and how fast a nanomaterial reacts in the environment and hence little is known about how long it is present in its original form.

3.5 How is the exposure level determined?

At present, app. 21,500 substances are registered in the EU. They are placed on the market in consumer products as substances, mixtures or articles. Humans and the environment could generally be exposed to all of these substances. However, the actual level of exposure depends on if and to what extent they are released from the products. Substances are often released quickly and “completely” from chemical products, e.g. washing powder is emitted with the washing machine’s wastewater. If they are included in articles, substances are usually released more slowly with a share remaining in them until they are disposed of and potentially destroyed during waste treatment, e.g. in an incineration plant.

Due to the high number of substances (and nanomaterials) and the even more and more divers products they may be included in, it is impossible to measure the exposure levels of these substances. Measurements are only conducted in specific cases,

e.g. at workplaces where chemicals are handled or if substance concentrations in the environment are monitored.

In most cases, the exposure from a substance is estimated or modelled. EU-wide agreed rules exist for these so called exposure estimations or models. The estimation/modelling results are predictions of the average substance concentration in the air, in surface waters, in foodstuff etc.

The **exposure assessment is also performed for nanomaterials**. Due to their small size and high reactivity, measuring nanomaterials is even more difficult than for macroscale substances (c.f. above). The exposure predictions are also more complex and involve higher uncertainties, among others because of the nanomaterials' reactivity and the resulting shorter (or longer) presence in the environment. It is also not fully clear, how nanomaterials behave in the environment or the human body. Finally, the existing (computer) models to calculate exposures are not yet fully adjusted to the specificities of nanomaterials.

3.6 Risk assessment

In order to assess a risk, information on a substance's hazards and possible exposures are combined. If the predicted exposure levels of humans and/or the environment are as high as the dose or concentration at which the substance causes an adverse effect, one speaks of a risk. This step is the same for nanomaterials and substances at "macroscale".

Consequently, communicating that a product contains a nanomaterial does not necessarily mean that it poses a risk. Finding out if this is the case requires a more in-depth evaluation.

4 Who has to Assess Risks?

The EU-wide applicable chemicals legislation consists of several regulations.¹¹ It places the responsibility for the assessment of risks from the uses of substances on the companies, which manufacture and market them. In addition, the "General Product Safety Directive¹²" states that the companies marketing consumer products (chemicals and articles) are responsible for their safety.

Companies have to compile all available information on the substance's hazards and under certain conditions may have to complement it with new data (e.g. from testing).

¹¹ In addition, there are some national laws, such as substance bans or specific labelling requirements.

¹² Directive 2001/95/EC on the general product safety.

They must use all available data to classify and label chemicals.

If and to which extent companies have to assess the risks from the use of their substances depends on the use of the substance. The application determines with which legislation the placer on the market and the users of a chemical have to comply with. Specific regulations with differing risk assessment requirements exist for example for pharmaceuticals, plant protection products or cosmetic products. These regulations also differ on whether or not:

- authorities control the risk assessment to decide if a chemical may be placed on the market (authorisation or approval) or
- whether the companies decide if and for which uses/products they take responsibility and place them on the market.

5 What needs to be considered for nanomaterials?

Legally speaking, nanomaterials are chemicals and are therefore covered by EU chemicals legislation. Like any other substance, they have to be classified and labelled. However, for many nanomaterials (like for many “macroscale” substances), information is insufficient for a complete classification. Therefore, it is only possible to communicate those hazardous properties, which can be determined based on that information. Which properties are unknown due to missing information normally cannot be identified by laymen.¹³

The content of nanomaterials needs to be identified on the packaging of some types of consumer products. This is the case for:

- Foodstuff,
- Cosmetics and
- Biocides¹⁴.

Substances at “nanoscale”, which are contained therein, have to be identified on the list of ingredients using the addition of “[nano]“. At present, hardly any products are labelled in this way.

No labelling requirements exist for consumer articles that do not contain any nanomaterials or any other hazardous substance.

Information about the content of nanomaterials in consumer products does not specify whether or not the respective nanomaterial has hazardous properties and/or

¹³ Respective information is published in a database by the EU chemicals agency. Interpreting it requires expertise that exceeds the normal understanding of “chemistry”.

¹⁴ Biocides are chemicals that are designed to kill organisms. They include products like disinfectants or pest control agents.

if a risk could occur from the use of the products. As long as nanomaterials are firmly bound to the products and/or do not have any hazardous properties, their content can be evaluated as “not problematic”. In addition, all producers should always ensure that their products can be used by consumers without harm.

6 Additional Information

Information on chemicals legislation

- EU-Commission: http://ec.europa.eu/environment/chemicals/index_en.htm
- German Federal Environment Agency (only German):
<https://www.umweltbundesamt.de/daten/chemikalien>

Further details on (the regulation of) nanomaterials' properties

- Federal Environment Agency:
<https://www.umweltbundesamt.de/en/topics/health/environmental-impact-on-people/nanomaterial>
- DaNa2.0 – Information on nanomaterials and nano safety research
<https://nanopartikel.info/en/>
- European Chemicals Agency:
<https://echa.europa.eu/en/regulations/nanomaterials>
- Institute for Risk Assessment:
https://www.bfr.bund.de/en/health_assessment_of_nanotechnology-30439.html

Nanomaterials in everyday life

- BUND (only German):
<https://www.bund.net/chemie/nanotechnologie/nanoprodukte-im-alltag/>
- Verbraucherportal Baden Württemberg (only German):
<https://www.nanoportal-bw.de/pb/,Lde/Startseite>

NanoDialogue of the German Government

- Ministry of the Environment, Nature Protection and Nuclear Safety (BMU):
<https://www.bmu.de/en/topics/health-chemical-safety-nanotechnology/nanotechnology/the-nanodialogue/>