HUMAN HEALTH RISK FACTORS ASSOCIATED WITH THE APPLICATION OF NANOMATERIALS – A REVIEW

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Abstract

During their application, behavior of nanomaterials can differ from the generally known, widely applied, considering their risks, familiar, legislated materials. Since they gained importance rapidly, we did not have enough time to study the mechanism of action of these materials in details. The short- and long-term effects of these materials are only scarcely known or not known. However, since the middle of the 2000s decade, an increasing trend can be noticed regarding the scientific literature dealing with the risk assessment of nanomaterials. It is important to pay special attention to the full life-cycle of the nanomaterials and to know the short- and long-term effects of some processes like mining, production, application, deposition, neutralization on our environment and on the health and security of the directly or indirectly affected people. In our paper we examine in detail the effects which can have an effect on human health and safety during the application of nanomaterials. We summarized the collected parameters to be tested, and we cathegorized them into topic areas in order to give assistance in the preparation risk assessments associated with nanomaterials, thus even the laymen can have a good overview on the critical factors in aspects of human health.

Keywords: *nanomaterials, safety, risk, clay minerals*

1. Introduction

It can be said that the regulation of application of nanomaterials is incomplete, however, from 1st January 2020, there are relevant laws for the companies that produce or import nanomaterials (1907/2006/EK, REACH regulation). 1272/2008 (CLP regulation) can also be considered relevant (ECHA, 2020).

Though the Council Directive 89/391/EEC does not include regulations for working with nanomaterials, it implies obligations for employers to ensure the safety and health of workers. It is obligatory for the employer to implement all measures which ensures the safety and health of the workers, including providing information, education, work organization, prevention of risks arising from different employments, and to make all necessary tools available. The potential risks should be avoided, if it is possible, the possible risk factors should be eliminated. In case of there are still risk factors remaining, a report should be written on them. If it is possible the hazardous substances and factors should be substituted by harmless or less hazardous ones. Collective protection should take over individual protection. The employer has the obligation to provide information for the workers and their representatives in case of emergence of working at hazardous conditions. Technological development should be observed and adapted. Tasks should be determined in accordance with the skills of the employee. It should be ensured that only an employee with the adequate education, qualification and instructions should enter an area where severe or special hazards occur. The employer has the obligation to provide protective and preventive services and to ensure that its actions do not jeopardize the health and safety of the workers and itself (Council Directive 89/391/EEC).

2. Short introduction of nanomaterials

Nanoparticles, considering their behavior, can be different from their macro-size equivalent, depending on their shape, size and structure. The characteristics which triggered the increasing growth of the application of nanomaterials can be potentially significant risks as well to the environment, the biosphere, these include human health, animal health or ecological risks. Our knowledge about the risks are incomplete, therefore, in the fields of occupational health and safety, the establishment of a new protocol about working with nanomaterials is hampered by several problems. We do not have exact knowledge about the potential risks one characteristic can bear.

Nanomaterials are the materials whose spatial extension is in the 1 nm-100 nm interval in at least one direction, however, in many cases, this interval is defined as the diameter of the particle (10 nm=10-9 m) (Bartis & Landree, 2006).

Many of these materials have special physical and chemical properties, thus, they can be found in many fields of the industry, e.g. pharmaceutical industry, energy production and storage, telecommunication, electronics, environmental protection, medical science, they can be applied as different food additives and soil conditioners, and also in cosmetics (Bartis & Landree, 2006).

The number of atoms and molecules constructing the nanoparticles significantly influence their physical and chemical properties. Size, particle size distribution, crystal structure, porosity, composition, aggregation/agglomeration state, the shape, surface, reactivity of the particles, binding energy, ionization potential, the surface charge (which can be characterized by zeta-potential), dissolution, solubility, dispersability, melting point and different optical properties are the parameters which can play an important role in the determination of the behavior of the particles. The mentioned properties are referred to as size effects, which are responsible for the differences between macro-size and nano-size materials. The size effects can be divided into two groups: internal and external size effects. Internal size effects are originating from inner characteristics, while the external ones are the feedbacks on external effects (Bárány, 2014; Wholleben et al., 2015).

2.1. Physical properties of nanomaterials

In a given medium, nanoparticles construct a nanosystem whose properties can even significantly differ from the properties of the present atoms, molecules and the macrosystem. Table 1 shows some nanoparticles and the corresponding nanosystem as examples (Bárány, 2014).

Table 1. *(Bárány, 2014)*

NANOPARTICLES	→	**NANOSYSTEM**
polymer molecules	→	sols, gels
protein molecules	→	aggregates, solutions
fullerenes	→	crystals
nanocrystals of inorganic materials	→	aerosols, colloid solutions
micelles	→	colloid solutions
nano-blocks	→	solid materials
Langmuir-Blodgett films	→	surface film on substrates
clusters in gases	→	aerosols

Depending on the desired quality, the particle sizes of the component of the investigated sample or its behavior, the physical properties of the particles can be determined for example with scanning electron microscope (SEM) or transmission electron microscope (TEM), using the method of dynamic light scattering, or even with X-ray diffraction (Wholleben et al., 2015). The nanoparticles can be characterized by their great specific surface area, which is their surface area related to their weight or volume [m2/g, m2/cm3]. The higher this ratio, the higher the reactivity of the material. The particles can adsorb pollutants on their surfaces, as a consequence, they can get into living organisms, however, this property results in their applicability in therapeutics (Wholleben et al., 2015).

The physical and chemical properties of the nanomaterials are primarily affected by the size and size distribution of the particles (Wholleben et al., 2015).

The small particles can form an aggregate by covalent bonds and Van Der Waals forces. In this state, the external surface area of the aggregated particles is much lower than the sum of the surface area of the individual particles. The probability of the aggregation depends on the probability of the collision, the collision frequency, the released mechanical and heat energy during collision, the properties of the medium (e.g. pH, temperature, components) (Wholleben et al., 2015). During manufacturing processes, the end-products can be in several form, which can significantly influence its behavior, physical and chemical products. It can be proved by experiments that materials of the same compositions, but of different particle shapes, can trigger different responses in living organisms (Wholleben et al., 2015). The shape of the particles can be the following: dendrimers, graphene, fullerenes, nanotubes, single-wall and multi-wall carbon nanotubes, nanofibres, nanoplates, nanorods, quantum dot, nanopowders (Kaluza et al., 2009)

Melting point is of high importance during industrial applications. With decreasing the size, the melting point can be significantly lowered, even by hundreds of degrees Celsius. Fig 1. shows the melting point of gold nanoparticles as a function of particle diameter (Bárány, 2014).

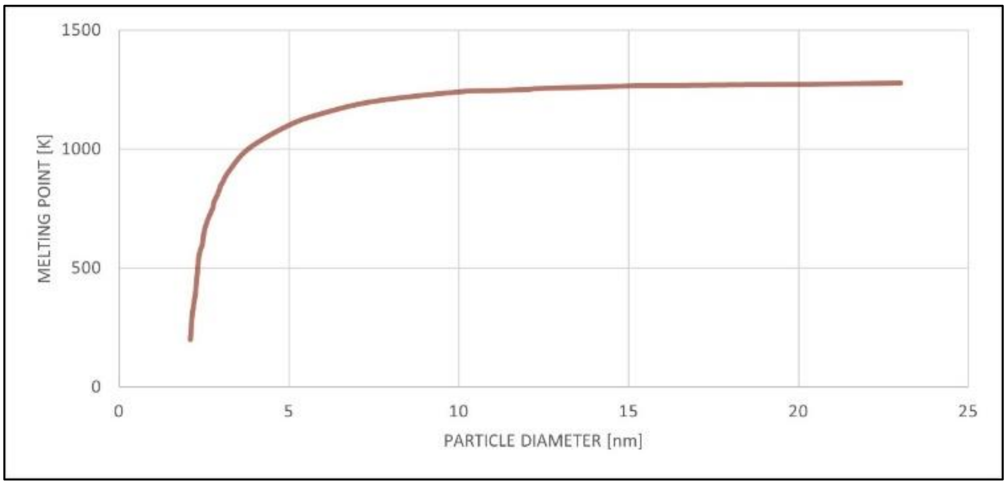


Figure 1. *Changes in melting point as a function of particle diameter (own edition of the authors, following Bárány, 2014)*

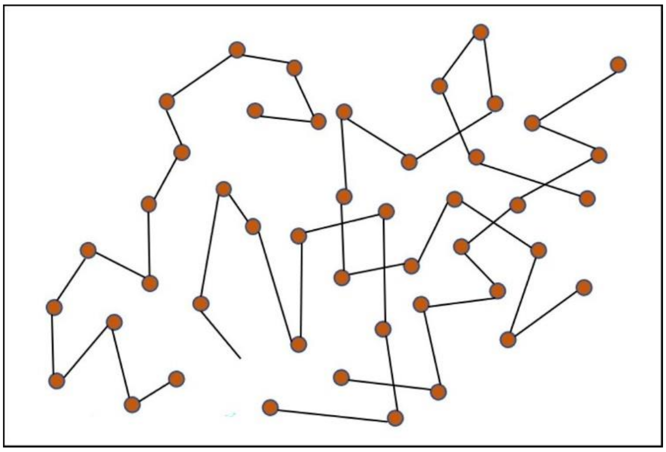


Figure 2. *Brownian motion (own edition of the authors, following Bárány, 2014)*

Nanomaterials also have unique optical properties. These parameters are usually investigated by a spectroscope, thus, the changes in the electron configuration of the given sample can be monitored (Bárány, 2014).

The nanoparticles move in a random Brownian motion, which is a continuous chaotic motion where the path of the particles cannot be determined by the known principles (Fig. 2).

Apart from this a rotation around the axis of the particles can also be observed, which is originating from the internal properties of the material. Actually, the Brownian motion is the translation of the particles, i.e. their thermal motion. The mobility of the particles is the function of their weight, the temperature of the medium and the viscosity. Therefore, the lighter the particle, the higher the temperature and the lower the viscosity of the medium, the higher the intensity of the motion. The smaller the particle, the greater the dislocation (Bárány, 2014).

2.2. Chemical properties of the nanomaterials

The behavior of the nanomaterials is the determined by the chemical composition, the crystal structure and the presence of incidental pollutants. Depending on the crystal structure, the same material can be both toxic and even totally harmless (Wholleben et al., 2015). Surface properties of the material influence their aptitude to interact with other particles, and determine the potential to stick to each other or to unite during collisions, i.e. to form an aggregate or an agglomerate. The cohesive forces are stronger in case of aggregates, while they are weaker for agglomerates, as it is depicted in Fig. 3 (Wholleben et al., 2015).

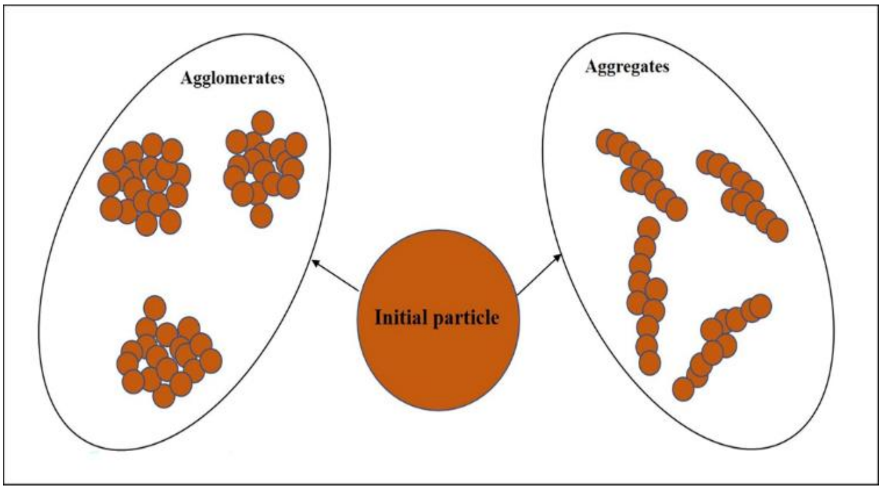


Figure 3. *Agglomerate and aggregate (own edition of the authors, following Boverhof et al., 2015)*

Surface charge determines the ion and molecule adsorption capacity of the particles. During aggregation the size increases, thus, the specific surface area decreases (Wholleben et al., 2015).

The distribution of the particles in our environment and in living organisms changes as a function of dispersability and solubility. These two parameters are the function of the pressure, the temperature and the pH. During the investigation of the materials, it is important to separate these two processes (Wholleben et al., 2015).

The composition of the nanomaterials can be the following:

- carbon based: these materials fundamentally contain carbon. Their shape can be ellipsoid, small spheres or cavernous tubes. Graphene, carbon nanofibers, nanotubes, fullerene, industrial soot and carbon particles with onion-like structure belong to this group. Their synthesis can occur via arc discharge, laser ablation or with a chemical method: by separating the steam phase.
- inorganic based: metals (silver and gold particles), metal oxides (TiO2, Zn) and semiconductors belong to this group.
- organic based: these group contains materials which mostly consist of organic matter, like micelles, liposomes, dendrimers and polymers. Carbon based nanomaterials are not part of this group.
- composite based: multi-phase materials belong to this group. They can consist of more types of nanoparticles or they can be combination of nanoparticles and larger or bulk-type materials or more complicated structures (Jeevanandam et al., 2018).

The origin of the nanomaterials can be natural or synthetic.

- Natural nanomaterials: they are produced in the nature by living organisms or anthropogenic activities. These nanoparticles can occur everywhere on the Earth, in surface or sub-surface water bodies, crust, rocks, soils and in the atmosphere. They can occur in the biosphere as well since the mentioned components are present in microscopic and macroscopic living organisms, including the human body.
- Synthetic nanomaterials: the group of synthetic nanomaterials consist of synthetized grains of different shapes. The method of production of these materials can be chemical, physical, biological or hybrid. The exhaust gas of the engines using hydrocarbon-based fuel also belongs to this group (Jeevanandam et al., 2018).

3. Health risks of nanomaterials

If during work we are in contact with nanomaterials in any form, or if we work without the necessary provisions, we are exposed to harmful health effects to a higher extent than to people living around us.

Due to the small size of the nanoparticles, after inhalation, they can enter the blood stream without any hindrance, reaching the organs by this. The origin of the particle also determines its potential harmful effects, therefore, some of them can be excessively harmful, less harmful, albeit some of them can also exert beneficial effects in the organisms (Jeevanandam et al., 2018). If foreign matter enters the organism, the immune system has a response.

It was discussed in different research works that the toxic effect of nanomaterials is not only the function of the dose. Differently from one of the basic principles in toxicology, it is also the function of the total surface area of the particles and the total weight of particles in a given unit. The size of the particle determines its aggregation potential, therefore, its effects as well, i.e. the larger the particle, the higher its aggregation potential, the lower their specific surface area, the smaller its harmful effect to the living organisms. Apart from the size, the appearance and shape of the particle also play an important role. Crystal structure can influence the behavior of the materials as well. For instance, if we consider the two mineral structures of TiO2 with the particle size of 200 nm, it can be observed that rutile can cause damage to DNA, while anatase does not have this effect (Nagymajtényi, 2013).

Considering health risk issues, metal oxide nanoparticles should also be mentioned, which are in some cases significantly different than their normal size equivalent. This property can provide its widespread application; however, it also means potential risk factor. These metal oxides can be found in everyday products as well, improving and preserving the quality of the product.

If the characteristics of macro-size metal oxides are taken into consideration during the determination of the properties of nano-size metal oxides, misleading information can be obtained, thus, the mechanism of action of the particles it would not be appropriate to make conclusions only from them. These materials can have effects on our environment which cannot be forecasted without adequate knowledge and experience (Wholleben et al., 2015).

3.1. Nanoparticles entering the human body

If during work we are in contact with nanomaterials in any form, or if we work without the necessary provisions, we are exposed to harmful health effects to a higher extent than to people living around us.

There are several routes by which nanomaterials can enter the human body, as it is shown in Fig. 4 below. In this research work the inhalation, the dermal contact and oral uptake (swallowing) are discussed in detail; the ocular uptake (exposure via eyes) and intravenous exposure are less relevant from the point of view of work.

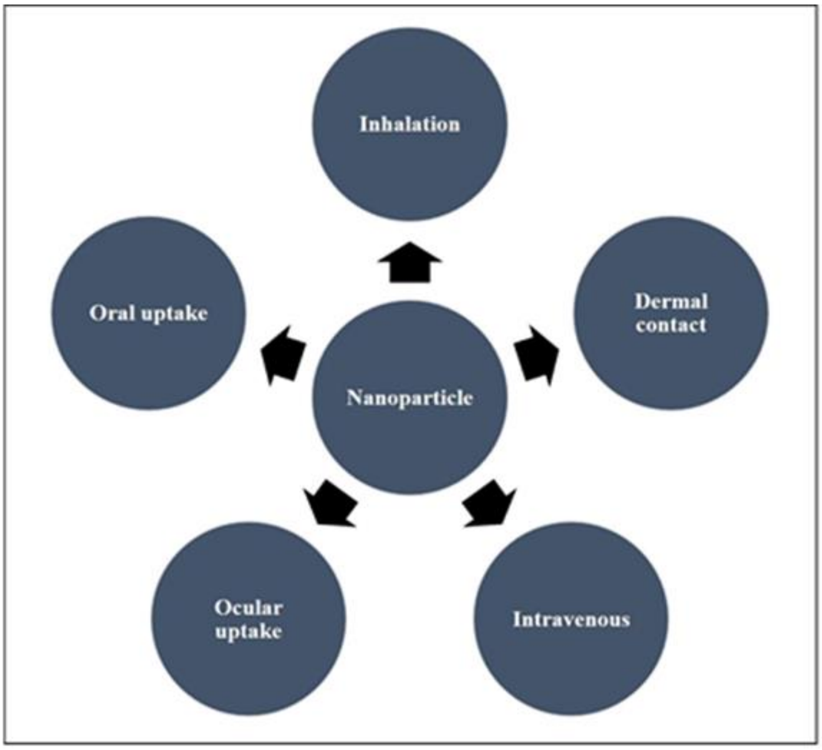


Figure 4. *Exposure routes of nanoparticles (own edition of the authors, following Chen et al., 2018)*

3.2. Effects of different nanomaterials on living organisms

Effects of nanomaterials on living organisms are tried to be studied by in vitro and in vivo experiments. Zebra danio, mice and rats are commonly used for tests on living animals, due to their favorable properties.

The particles trapped in the interstitial space after entering the body, which cannot be eliminated by the phagocytes, can lead to long-term inflammatory symptoms, which can result in further negative health effects. Oxidative stress can also occur as a further possible effect, which evolves by different physicochemical processes, due to the high specific surface area of the particles and the reactivity of the surface. Evolution of cancer can be partly attributed to the production of free radicals, which involves DNA damage, which is permanent in many cases. Allergic reaction can occur after the inhalation of nanomaterials, since due to their high specific surface area, different materials can be absorbed by them, including allergens as well. Accumulation of nanoparticles in the lungs can cause asthma. In case of regular exposure, if the symptoms are already present and the disease has been diagnosed, the state of the patient can be worsened, and emphysema, chronic airway inflammation, abnormal multiplication of cells can also occur (Nagymajtényi, 2013).

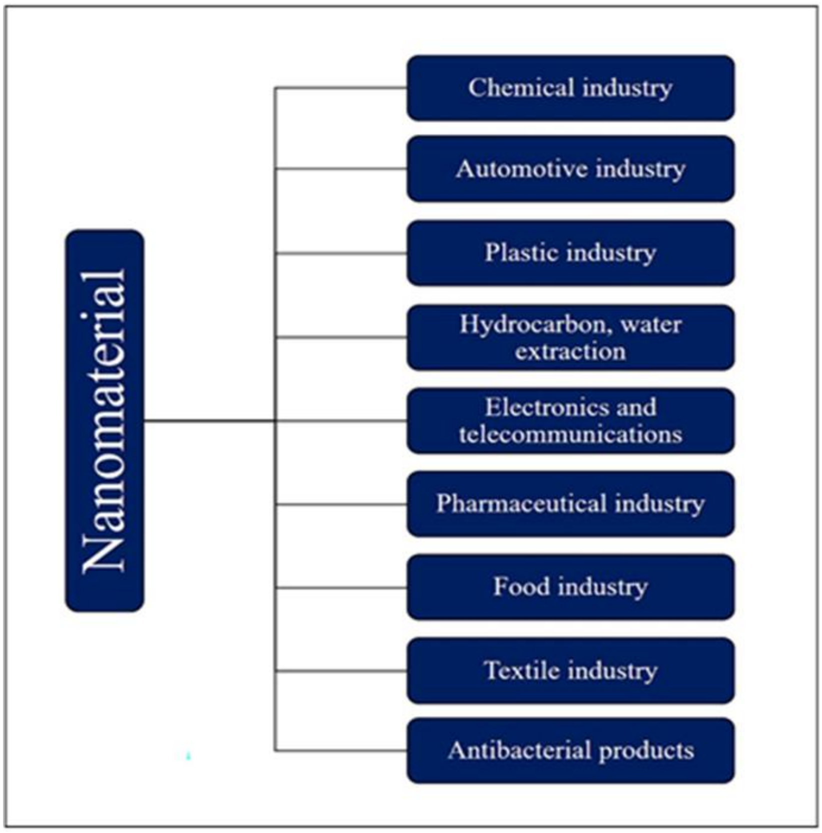
After exposure nanoparticles can also be the cause of cardiovascular diseases, due to oxidative stress. Inflammation can also occur in the heart, which can cause damage to the epithelium, it can lead to equilibrium disturbances, excessive plaque formation occurs, which can get off the blood vessel walls, resulting in thrombosis. After the nanoparticles get through the heart muscle cells, it can trigger arrythmia (Nagymajtényi, 2013).

The particles, via the olfactory epithelium of the nose, enter the brain and the nervous system directly, which can lead to the functional damage of the central nervous system (Nagymajtényi, 2013).

The particles entering the lymphatic system can clog the lymphatic vessels, which can cause lymphatic edema (Nagymajtényi, 2013).

4. Investigation of the work involving nanomaterials

There are several industries which use nanomaterials (Fig. 5): chemical industry, healthcare industry, automotive industry, electronics industry, and telecommunications industry, textile industry are the most important ones, along with industries aiming at effective energy storage. There is an increasing demand in the nano-field (Kaluza et al., 2009).



1. Figure. *Possible utilization of nanoparticles (own edition of the authors)*

To ensure the safety of working conditions it is necessary to perform an airspace analysis, which is, in this case, not the traditional concentration measurement, since it does not influence the effect of the particles, and there is no device which is available to perform this in the <1 µm particle size interval. However, there are devices which can analyze the materials in the atmosphere in a different way (Kaluza et al., 2009).

During the analysis it should be distinguished which materials originate from outside the industrial area and which are not released during the manufacturing process (Kaluza et al., 2009).

During the synthesis of nanomaterials, the possibility of the inhalation of the material is relatively low, since such processes take place in a closed system. However, if there is a leakage during a malfunction for instance, it can be an exemption. Contact with the material occurs more likely after opening the chamber during drying, further treatment or chamber cleaning (Kaluza et al., 2009)

Different maintenance processes are one possible way for getting into contact with nanomaterials during work, in this case, nanomaterials enter the human body mainly via inhalation. Such work phases can include:

- performing a task which can cause the release of the material, e.g. polishing or grinding
- using chemicals which contain nanomaterials
- maintenance, repairment of devices which are in contact with nanomaterials (EU-OSHA, 2013).

During utilization of dust or during the cleaning process of dust collectors, particulate matters can get into the workspace, thus, they can enter the human body via inhalation, oral intake or dermal contact (EU-OSHA, 2013).

In case of liquid materials, for instance lubricants, greases, paints, surface treatments the same contact and intake ways may occur. The work process can be preparation, using the material itself or cleaning up the spilled product. During preparation works, if it involves pouring, stirring or shaking, aerosols can be released, or during application, spray can be formed.

During different surface treatment tasks, the matrix structure can be damaged, therefore, particles can be released to the atmosphere, which can enter the human body then via dermal contact, oral intake or inhalation (EU-OSHA, 2013).

In presence of dusts and aerosols the risk of fire and explosion can also occur, a special attention should be paid to this (EU-OSHA, 2013).

If there is a possibility of contact or mixing of two materials in the same / different states of matter, the following dispersed systems can be formed (Fig. 6).

The extent to which the workers or the people at the workplace are exposed to any kind of contact, inhalation, oral intake, dermal contact with the certain material(s) is the function of the appearance, the state and the distribution of the particles, the contact time (the time spent inside the area/room) and the method / absence of ventilation. If the exposure is increasing, the occupational health risk is higher as well (Fig. 7).

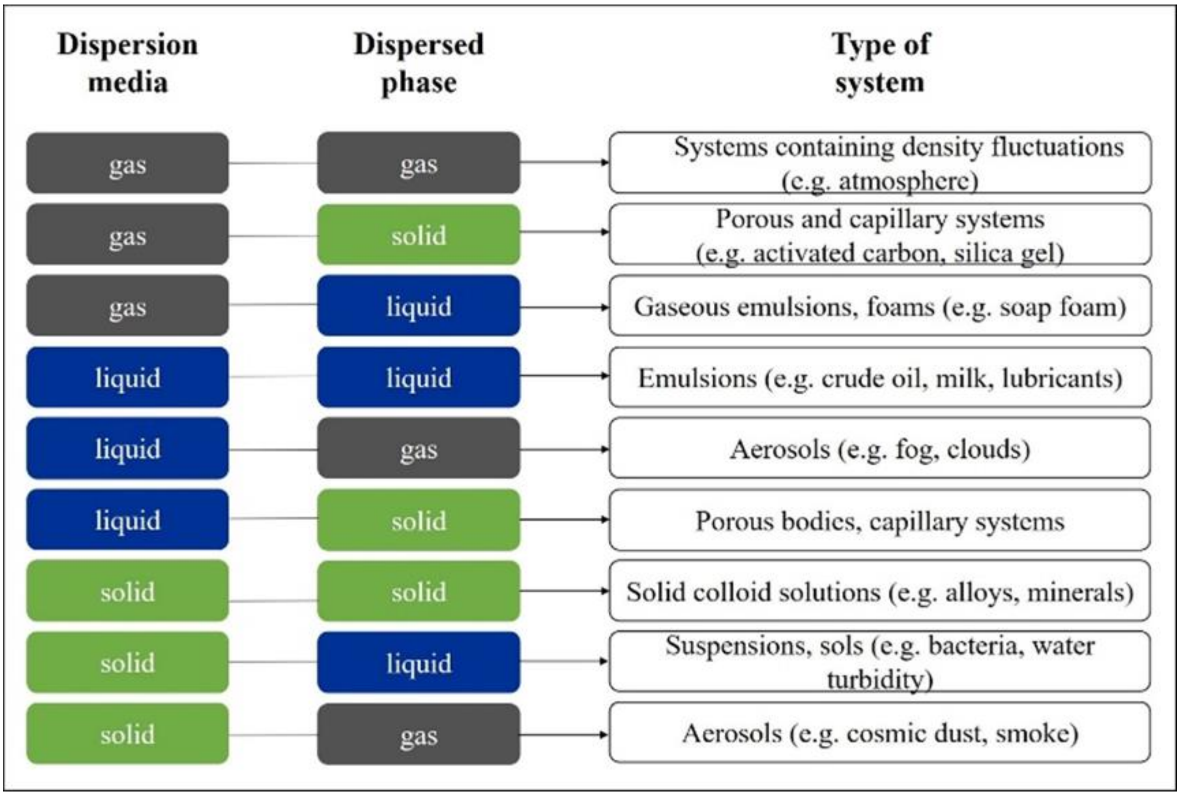


Figure 6. *Types of dispersed systems (own edition of the authors, following Bárány, 2014)*

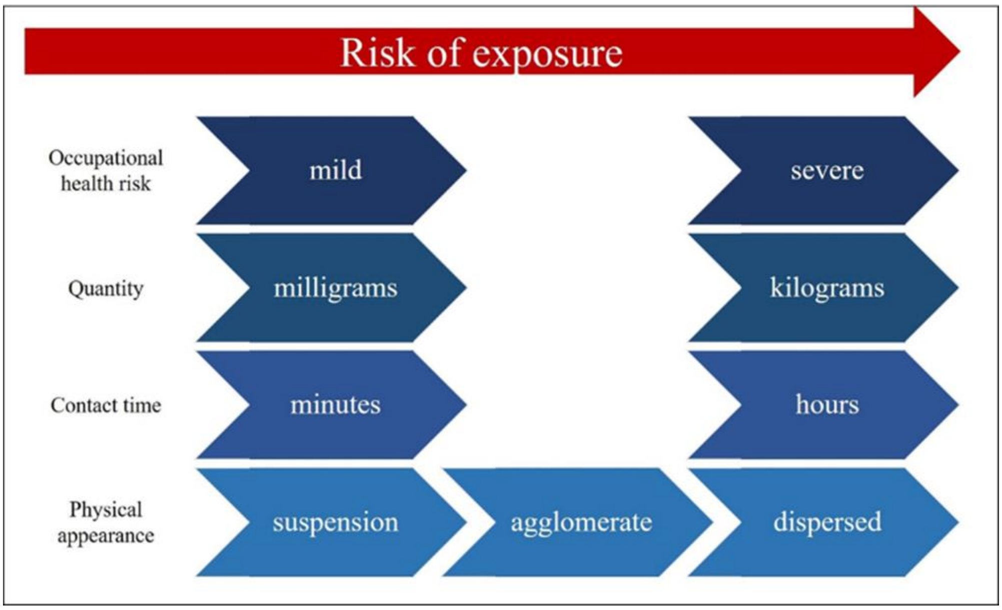


Figure 7. *Extent of exposure risk (own edition of the authors, following NIOSH et al., 2016)*

4.1. Tasks related to risk assessment and evaluation during work with nanomaterials

If during work there is a potential risk of contact with nanomaterials, it is very important to know, to examine and regulate the material in detail, to which the following statements can contribute.

If the structure of the particles is fibrous, tubular, or during visual inspection, filaments or rods can be observed, then it can be assumed that these materials can behave like asbestos-like minerals, thus, the same procedure can be considered to be applied to them. (Bridges et al., 2009)

During the assessment different risk categories can be formed, to which different materials can be classified. Due to the fact that there is insufficient information available, a complete categorization cannot be performed, during the process, several hindrance factors may occur, therefore it is necessary to know the materials and their mechanism of action as accurately as possible, and then, properties of known materials can serve as bases of comparison (Bridges et al., 2009).

In case of well-known materials, during risk assessment, usually the worst case is assumed, thus, the risks are overestimated (Oomen et al., 2018).

If the employees are potentially exposed to contact with nanomaterials, periodical medical examinations should be conducted, including blood, urine and respiratory system tests.

A nanomaterial records inventory list should be kept (similarly to chemicals inventory list) about the nanomaterials used in the work area. Safety data sheets are required along with a documentation on which the properties of the material are listed. The data and contact information about the manufacturer should be available; all common and chemical names of all hazardous components, all physical and chemical characteristics of all components, potential carcinogenicity, mutagenicity, teratogenicity, potential inhibition of reproduction and other factors which are harmful to health along with the related diseases and symptoms should all be known.

The probability, the frequency and the extent of the exposure should be investigated, grouped by exposure routes, i.e. the potential risk of exposure of the employee to oral uptake, inhalation, dermal contact and even the combination of these, along with the different reference limit values. The investigation may involve the potential risk of ocular uptake or intravenous exposure, e.g. in case of an injury.

As a first step, data should be collected, all properties of the examined material should be presented. Data collection may involve summarizing the own available data of the substance, the laboratory measurement results or data of similar materials.

Key parameters are the chemical, physical, reactivity properties along with the basic behavior features, these play an important role in determining the characteristics of the substance. Chemical composition implies the components and the crystal structure. Among surface properties the surface charge should be first mentioned, however, if the material is treated, the characteristics and function of the coating can also be important, along with the presence of other impurities. As for physical properties, particle size, particle shape, particle size distribution and surface area (including porosity) play an important role. Reactivity includes physical hazards, flammability, explosiveness, spontaneous combustion, biological response of the organism and photoreactivity. Dissolution, solubility, hydrophobicity, dust formation potential and dispersibility are referred to as basic behavior features. It is obvious that not all parameters are relevant for each substance. All possible exposures should be assessed which can jeopardize the employers and all other people staying in the work area. The properties of the material can be denoted by weights, which can promote a more accurate assessment of the risk of the contact. The collected data should undergo an evaluation process (Oomen et al., 2015).

It should be indicated in all cases if the material is flammable or explosive, besides, information about maintenance and cleaning, different measurement methods, protective equipment should be included along with transport and storage information and the date of manufacturing. An action plan should be written on which the personal tasks of the employee are listed. Vulnerable groups should be taken into account when the work process with the nanomaterials is planned or the exposure is assessed, and it should be considered if any special measures should be taken regarding them. To create a safe workplace, on the basis of legislation a priority list should be prepared, which is actually the hierarchy of measures. (Eastlake et al., 2012; EU-OSHA, 2018)

All work phases should be taken into account where the possibility of exposure can occur. It is recommended compare the product material and the starting material in terms of hazardousness and toxicity. The substances can be grouped and ranked according to the purpose of application, the physical appearance, the properties of the applied medium and the potential exposure routes. The evaluation should be performed by avoiding subjectivity, by getting clear, well-interpreted results; to do so, the reliability of the sources should be assessed (Stone et al., 2020).

5. Recommendations

In workplaces where the risk of contact with nanomaterials is present in any form, a risk assessment should be carried out. As in case of hazardous materials, activities and devices, nanomaterials and the related processes should be investigated as well. There is no fully developed evaluating criterion system for such systems, however, it is of high importance. Since it is a 'new' material, there is a significant uncertainty, which should be reduced in the fastest possible way. A thorough and detailed guideline is needed which can be generally applied in the industries concerned.

In case of high risk, the work process should be stopped and paused until the danger is eliminated and the risk has been reduced. The risk which is persistent even after the measures is called residual risk. In such cases the danger cannot be further reduced since at that time the investigated element or process loses its property for which it is applied in the technology. This risk should be accepted and it should be indicated on the safety data sheet (or on an equivalent document).

To support the risk assessment processes of the nanomaterials we compiled an investigation criterion system where the investigated factors and properties are grouped by subjects. It is important to be highlighted that in the criterion system compiled by us there were no references to the extent of the risk, since the nanomaterials can vary type by type. Only a general summary is presented by us, which serve as a guideline during the evaluation process. The criterion system compiled by us is presented in the Table below:

Table 2. *Summary of risk factors regarding nanomaterials*

Num.	Subject	Investigated factor	Property
1	General properties	safety data sheet	-
2		employee concerned	young employees
3			elderly employees
4			female employees

5		exposure (40 hours a week, 8 hours of working time per a day)	-
6		average concentration limit	exceeding limit value
7		peak concentration limit	exceeding limit value
8		concentration in the atmosphere of the workplace	-
9		number of types of materials in the atmosphere	formation of disperse systems
10		probability of exposure	-
11		frequency of exposure	-
12		dose	-
13	Physical properties	shape	rod/ fiber/ filament/ tube
14			single-wall nanotubes
15			multi-wall nanotubes
16			sphere
17			quantum dot
18			plate
19			dendrimer
20			needle shaped or radial
21			fullerene
22			cube
23			triangle
24			star-shaped
25			shell structure
26			film
27			irregular
28		shape	0D

29		(1-100 *nm*)	1D
30			2D
31			3D
32		state of matter	liquid
33			solid
34			gaseous
35		density	-
36		particle size distribution	well graded
37			poorly graded
38		surface properties	specific surface area
39			porosity
40			roughness/ unevenness
41		elasticity (e.g. Young's modulus)	-
42		electric conductance	-
43		magnetism, magnetic susceptibility	-
44		fotoactivity	-
45		optical behavior	-
46		sedimentation rate	-
47		stability	disintegration/ fragmentation
48		hardness	-
49		formation of dust	-
50		melting point	-
51	Chemical properties	crystal structure	-
52		composition	carbon based
53			organic based
54			inorganic based
55			composite based
56		structural formula	-
57		surface coating	-

58		dissolution, solubility, dispersibility	-
59		aggregation, agglomeration potential	-
60		surface properties	-
61		redox potential	-
62		surface charge (e.g. zeta potential)	-
63		hidrophylic	-
64		hidrophobic	-
65		lipophylic	-
66		lipophobic	-
67		stability	-
68		reactivity	interaction with other particles
69		formation of free radicals (ROS-Reactive Oxygen Species)	reaction with other particles
70		impurities	substances harmful to health
71		disperse system	hydrogel
72			aerosol
73			emulsion
74			solid colloid
75			suspension
76			gaseous emulsion
77			porous and capillary system
78			porous bodies, capillary systems, gels
79		self-purification	-
80		silicon dioxide	-

81	Material of particles	single-wall nanotube	-
82		multi-wall nanotube	-
83		fullerene	-
84		metal oxide	-
85		titanium dioxide	-
86		iron, iron oxide	-
87		silver	-
88		gold	-
89		zinc oxide	-
90		graphene	-
91		graphene oxide	-
92	Biological properties	respirable mean concentration limit (enters airways without ciliary epithelium)	exceeding limit value
93		inhalable mean concentration limit (full amount via nasal and oral intake)	exceeding limit value
94		reference limit in urine	exceeding limit value
95		reference limit in blood	exceeding limit value
96		inhalation	access to organs, accumulation
97		oral intake	access to organs, accumulation
98		dermal contact	access to organs, accumulation
99		ocular uptake	access to organs, accumulation

100		intravenous exposure	access to organs, accumulation
101		allergenic	-
102		mutagenity	-
103		carcinogenicity	-
104		teratogenicity	-
105		genotoxicity	-
106		neurotoxicity	-
107		damaging respiratory system	-
108		damaging endocrine system	-
109		inflammatory	-
110		persistence	accumulation
111		immunotoxicity	depends on application mode
112		hepatotoxicity	depends on application mode
113		renal toxicity	depends on application mode
114		immune system damaging	depends on application mode
115	Activity	production	-
116		physical processing	grinding, cutting, polishing, crushing/ shredding etc.
117		storage, deposition	-
118		transport	package
119		sampling	dust formation
120		filling, packaging	dust formation
121		maintenance and cleaning of equipment	dust formation

122		cleaning the workplace	dust formation
123		waste management	-
124		starting/raw material	-
125		end-product	-
126		by-product	-
127		ventilation	-

6. Conclusion

During the study of the properties of nanomaterials and nanoparticles we collected the factors, and within the factors, the parameters, which can have a significant effect on living organisms by affecting human health, thus, during the development of the criterion system, we concluded that the physical, chemical and biological properties of the nanomaterials should be investigated in a comprehensive way.

During the construction of the criterion system, we aimed at the investigation of the most characteristic properties that can be considered generally relevant.

Depending on the investigated technological process, the risks of working with the material / contact by the worker / staying inside the area range of work can be investigated according to the criterion system based on the basic properties of the nanomaterials.

The technological development and the new researches should be continuously monitored. The literature data base, the source documents should be updated in order to acquire the possible most up-to-date, thorough and accurate knowledge about the properties of the materials and substances applied and formed during work.

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