Safety Engineering Series, ISSN 1805-3238 pp. 25-37, DOI 10.35182/tses-2019-0009

CURRENT APPROACHES OF OCCUPATIONAL AND SAFETY HEALTH MANAGEMENT IN WORK ENVIRONMENTS CONTAINING NANOPARTICLES

Vladimír ADAMEC[1], Barbora SCHÜLLEROVÁ[2], Klaudia KÖBÖLOVÁ[3], Stela PAVLÍKOVÁ[4], Danuše PROCHÁZKOVÁ[5], Tomáš ZEMAN[6]

Review article

Abstract: The development of nanotechnology is particularly in recent years very dynamic and is applied in many not only technical branches. This is not possible to say about monitoring of possible health and environmental undesirable influence. The first area of possible risk assessment is work environment because there is a lot of possible ways to exposition. The aim of the paper is to analyze current situation in the field of occupational safety and health management in the workspace with occurrence of nanoparticles not only like the engineered nanomaterials. Because there is a lot of influence which could have the negative impact on the employee's health.

Keywords: OSH, work environment, nanoparticles, risk assessment, health.

Introduction

The goal of Occupational Safety and Health (OSH) is to ensure work environment conditions which aim to minimize safety risk to staff. The primarily used preventive and safety measures are of both technical and systemic character and are intended for individuals as well as teams. The general OSH principles include company strategy (legislation, tasks and aims, programmes, sets of assessed objects), identification, analysis and assessment of hazard, control and corrective measures (monitoring, checking, prevention, records, inspections, audits etc.), continuous monitoring of the results achieved (external and internal ones) and comparing them with the expected results (Aven, 2016; ČSN EN OHSAS, 2007). A functional policy of safe work environment is also based on securing the socio-technical system as a whole including people (employees) with all their qualities (education, ambition, reliability etc.) (Aven and Ylönen, 2018; Aven, 2017; Carayon et al., 2015).

The development of technologies brings the need for a higher level of OSH. New fields emerge, especially in industry, where sufficient safety and preventive measures have not yet been provided, nanoparticles being an example. The issue is not only the health risks related to direct exposure to these particles. It is also the psychological aspects of an employee, their perception of the safety level, stress, well-being, attention, productivity etc. in work environment containing nanoparticles. Another aspect which is not considered is the potential resulting risks such as the impact on the company operation and the economic side

[1] University of Technology, Institute of Forensic Engineering, Brno, Czech Republic, vladimir.adamec@usi.vutbr.cz

[2] University of Technology, Institute of Forensic Engineering, Brno, Czech Republic, barbora.schullerova@usi.vutbr.cz

[3] University of Technology, Institute of Forensic Engineering, Brno, Czech Republic, klaudia.kobolova@usi.vutbr.cz

[4] University of Technology, Institute of Forensic Engineering, Brno, Czech Republic, stela.pavlikova@usi.vutbr.cz

[5] Czech Technical Univerity in Prague, Faculty of Civil Engineering, Prague, Czech Republic, danuse.prochazkova@fsv.cvut.cz

[6] University of Defence in Brno, Faculty of Military Leadership, Brno, Czech Republic, tomas.zeman2@unob.cz

Safety Engineering Series, ISSN 1805-3238 pp. 25-37, DOI 10.35182/tses-2019-0009

connected with the employees' incapacity. The aim of the study is to analysed a current state of the OSH management system with the emphasis on the neccesarry of the increasing its standard and effectiveness in places which contain particles smaller than 2,5 µm. Currently there are methodologies and approaches in place for risks evaluations that are related to employee's health and safety, but they don't take employee's psychology (safety level perception, well-being, attention, performance, etc.) into account and at the same time don't consider possible subsequent risks (impact on business operations and economy).

OSH management and their tasks related to the occurrence of nanoparticles in work environment

Management of the work environment safety is a very complex system which requires the implementation of many supporting processes that must be further developed and enhanced to keep it fully functional for a long time. To achieve a functional system of OSH management, several different methods and tools can be used. Companies determine their own processes so that they can ensure the basic legal requirements using supporting tools (ČSN EN OHSAS, 2018; ČSN IEC, 1997; Mohammadfam et al., 2017). The current approaches select mainly proactive approaches with the emphasis on preventing the OHS related problems. We can see these new approaches being adopted especially in the form of various in-house policies in the sphere of OSH or Corporate Social Responsibility (CSR). Managers hereby undertake to keep developing the control processes and procedures designed for monitoring the OSH system. Although it could seem that it is only a marginal matter, such obligation to continually enhance the level of safety in the company combined with an active involvement of managers in these activities sets a very good example to the subordinates and may motivate them to follow their example. (Sheenan et al., 2016). The effectiveness of the OHS management systems is, for example, dealt with in the study. (Ghahramani, 2016; Zink, 2005)

Supporting the health of employees by a business entity aims to prevent unsuitable working conditions and minimize risks. It results in healthy employees, who give a better performance and are active longer and therefore become a significant economic factor in the company. Certain discomfort of the employees may result in damage to their health. Risk assessment of the work environment should therefore include the monitoring of the employees' complaints about excessive strain, decreasing work motivation, bad working climate, long working hours etc. (ZSBOZP, 2018). That is why it is necessary to approach risk assessment and prevention comprehensively.

However, the development of society and technologies (see Fig. 1) may also result in new risks previously unknown to the society and at workplaces. These risks and the related work activities must be assessed and dealt with. The impact of the occurrence of these particles on employees is the subject matter of some research results such as (Senčík et al, 2016; Mička et al., 2015; Skřehot and Rupová, 2011), which focus primarily on the related health risks. These negative effects include risks related not only to the physical health but also mental, certain discomfort, perception of the safety level, incapacity etc. All this may also result in an adverse economic effect on the entity. It is mainly the psychological aspects related to work safety that are pointed out by the European Agency for Safety and Health at Work, the World Health Organization or professional studies (EU-OSHA, 2018; WHO, 2018; Houtman et al, 2008). New technologies and the level of knowledge bring not only positive impact but also the risk of negative impact on humans and the society as such. Insufficient knowledge, awareness or incomplete and distorted information possessed by an individual or a group may result in hazards that need to be prevented. From the employees' point of view, the whole situation is also intensified by the fact that there are currently no limits regarding nanoparticles determined by legislation.

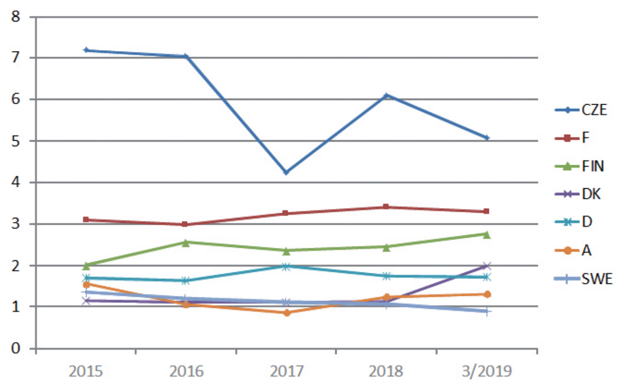

Fig. 1 Share of the Nanotechnology Patents to total patents [%] (StatNano, 2018)

Safety Engineering Series, ISSN 1805-3238 pp. 25-37, DOI 10.35182/tses-2019-0009

Nanoparticles in work environment and their impact on the health of employees

Nanoparticles are part of human life. They have always been on Earth, especially in a natural form, for example from volcanic eruptions. With the development of human society not only their origin began to change and people started to use them for example in the glass industry or civil engineering. It was not until the development of technology that these particles were observed, described and produced (Skřehot and Rupová, 2011). Especially in the recent years there has been a rapid development of nanotechnologies and their application in medicine, industry, power engineering etc. A uniform definition of the terms „nanotechnologies“ and „nanomaterials“ has not yet been provided and therefore the recommendation of 2011/696/EU is used within the EU:

"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 dimensions is in the size range 1-100 nm."

In relation to work environment we can divide the origin of nanoparticles or nanomaterials into 3 basic groups:

- nanoparticles and nanomaterials created through their direct production (so called engineered nanomaterials, ENMs),
- ENMs used for further production and treatment (additives in paints, parts of filtering materials, surface treatment of textiles and footwear, buildings etc.),
- nanoparticles created unintentionally during work processes (welding, grinding, combustion processes, melting or refining of metal etc.).

In the sphere of OHS and the assessment of related risks emphasis is currently placed especially on ENMs. However, the work processes during which nanoparticles are created unintentionally should not be ignored either. (WHO, 2017)

Risk assessment in work environment containing nanomaterials

The number of newly processed nanomaterials and their applications keeps increasing rapidly. When dealing with these materials, it is necessary to emphasize the importance of considering and controlling the potential undesirable and unacceptable impacts of nanotechnologies and aim to develop their possibilities and benefits. The main area of interest is the potential unacceptable impact on employees as they are the first in the company to be exposed to the potential risks posed by nanotechnology. OHS criteria defining a responsible development of nanotechnologies are needed. Schulte et al. (2014) introduces five critical actions that should be performed by decision-making authorities on business and social levels - if nanotechnology is to be developed responsibly. They include:

- anticipating, identifying and monitoring the potentially hazardous nanomaterials at the workplace,
- assessing the exposure of the employees to nanomaterials,
- assessing and reporting hazard and risks that the employees face,
- risk management focused on occupational health and safety,
- supporting safe development of nanotechnologies and realizing their social and commercial benefits.

All the above-mentioned criteria are necessary for ensuring responsible development. Considering the fact that the commercialisation of nanotechnologies is in the early phase, there are still a lot of unknown and worrying questions concerning nanomaterials. Therefore, it is prudent to treat them as potentially hazardous until sufficient data are gathered on the toxicology and exposure for the assessment of risk and risk specific to nanomaterials (Fig. 2). In this period of development the extent of uncertainty and the need for careful measures must be clearly determined.

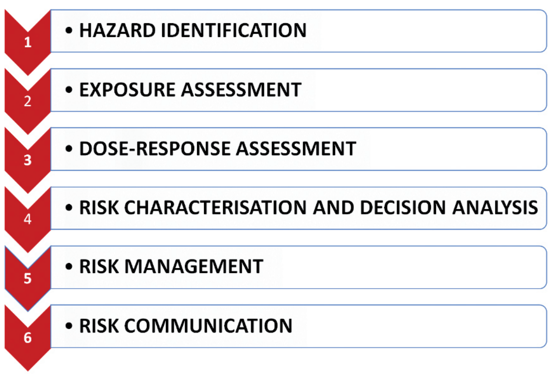

Fig. 2 General principle of health risk assessment and management

Safety Engineering Series, ISSN 1805-3238 pp. 25-37, DOI 10.35182/tses-2019-0009

The main power driving responsible development of nanotechnologies and each criterion is determination of the responsibility for safety in the workplace and exposure of employees. On company level it is the employer who is responsible for a safe and healthy workplace. When nanotechnologies started to be commercialised, a lot of employers said that they knew very little about the hazard, risks, exposure, and control related to nanomaterials.

This uncertainty related to the hazard and risk could have caused that a lot of employers did not take the appropriate measures to protect their employees This uncertainty concerning the risks prompted government agencies to provide instructions on this matter. Employees and their representatives are also obliged to advocate safe and healthy workplaces, encourage the effort to manage risks on the company level and take part in it, and advocate safety instructions on the social level. Society as a whole is responsible for supporting employers, employees, trade unions, governments and others in fulfilling their obligations. Besides that, the public must be informed and involved in talks on new technologies, especially in relation to the potential health risks which may be connected with this technology.

Appropriate care and legal mandates require that employers should be informed about the hazards that their employees might be exposed to and about all hazards in the facilities that they control (including nanomaterials and other chemical or physical risks). If there is any uncertainty about the nature, degree, and extent of the hazard posed by nanomaterials, it is up to the employers to know what nanomaterials are at their workplaces, to identify the processes during which exposure may occur, and to support studies focused on determining the biological activity of nanomaterials. This is not always an easy matter for the employers who might unknowingly use some components of products containing nanomaterials. (Schulte et.al., 2014)

Recent data show that important information regarding nanomaterials is not included in the current safety data sheets as is shown in Fig. 3 (Safe Work Australia, 2010b; Eastlake et al., 2012; Lee et al., 2012). Besides that, after the introduction of the Globally Harmonized System (GHS) of Classification and Labelling of Chemicals it is not clear how nanomaterials will be identified, classified and labelled. However, employers must consider the potential hazard related to the materials that they produce or treat. If there is any concern, the employer should use the current instructions concerning exposure control or look up expert information on taking appropriate control measures. To assess the potential health risk related to a certain material it is crucial to update the information about the new and changing information on its hazardousness.

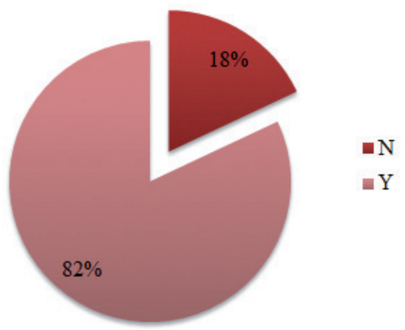

Fig. 3 The percentage of the total number of the safety data sheets where nanomaterial was put in the „dangerous“ (Y) and „harmless“ (N) categories. Group N also includes the safety data sheets for which no safety statement was made (Safe Work Australia, 2010b)

The basis of hazard identification is toxicological research. Responsible development of nanotechnologies requires further investment in such research. To ensure appropriate care in accordance with the TSCA in the USA or registration, evaluation, authorisation and restriction of chemicals (REACH) in the European Union, employers will have to continue investing in toxicological research into nanomaterials. On December 3rd, 2018 the new EU 2018/1881 regulation of the Commission was introduced, which responds to the development of the current nanotechnologies and various nanoforms. This regulation changes the 1907/2006 regulation of the European Parliament and Commission on registration, evaluation, authorisation and restriction of chemicals, namely in appendices I, III, VI, VII, VIII, IX, X, XI, and XII, in order to take into consideration the nanoforms of substances. These changes will come into force in January 2020. Combining toxicological testing with hazard determination is not new for the global chemical industry. The transition to the nano-level uncovered new or increased biological activity controlled by size and physical-chemical properties and employers will have to continue examining the role of these parameters in relation to toxicity. A better understanding of the relationship between the physical-chemical properties and toxicity will make it easier to assess the risks in new materials and to design safer nanomaterials. Tools for making categorical toxicity estimates such as various alternative testing strategies, quantitative structure-activity relationship models (QSAR), computational toxicology, and bioinformatics must be applied to untested materials with similar properties and used as a basis for initial risk management. (Makoto et al., 2017; Nel et al., 2013; Stone et al., 2013)

If the right decisions are to be made concerning the control of nanomaterials and the hazard and risk related to them, it is necessary to carry out scientific research in these areas (see Fig. 4). Considering the fact that the results of the tests of short-term toxicity of the first generation were used to predict the hazard of a small number of nanomaterials and to take measures for exposure control, in the final consequence, there is a need for standardized approaches to toxicological evaluation, specifying priorities for toxicity testing and long-term assessment; investigation (chronic health effects) (Van der Merwe, 2018; Savolainen, 2012; Bonner et al., 2013; Stone et al., 2013). If the degree of hazard has not been determined, the general instructions of government agencies should treat the candidate nanomaterials in their workplaces as if they posed a potential hazard, until a higher degree of certainty is available concerning the presence or degree of risk. If the extent of hazard has not been determined, the general instructions provided by the government agencies recommend treating specific nanomaterials in the workplace as potentially hazardous substances. (Philbrick, 2010; Schulte et al., 2012)

A critical factor in risk assessment and management is measuring the exposure to nanomaterials (Ramachandran et al., 2011). It is a comprehensive effort, especially in the early phase of the natural development of artificial nanomaterials, when it is not clear what the suitable exposure metric is (Brouwer et al., 2012; Ostraat et al., 2013). However, the latest instructions have suggested that the weight of particles/the volume of air can be a useful criterion for measuring the air exposure of nanomaterials. Since the first publication of the „NIOSH Approaches to Safe Nanotechnology“ document at the NanOEH2 symposium in Minneapolis in 2005 the government instructions on how to assess the exposure of staff and implement the risk management strategy have been continually improved and updated as soon as new information is obtained. (NIOSH, 2009a)

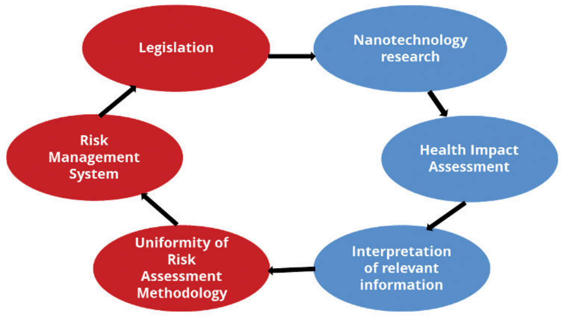

Fig. 4 Cycle of Risk Assessment Framework development and implementation (NIOSH, 2009a)

Last but not least, the kind of risk management procedures necessary for the protection of staff will depend on the extent of risk (Schulte and Ringen, 1984; Jonsen, 1991; NRC, 2009; Gibson et al., 2012). Risk is a probability concept depending on hazard (the degree of thereat) as well as exposure. Characterizing reliability and uncertainty in risk estimation is important for communication and risk management. Employers can carry out qualitative risk assessment by identifying where exposure to nanomaterials occurs and to what extent or by identifying possible exposure that could occur among their staff in their facilities. Moreover, quantitative risk assessment enables risk estimation based on empirical data. For QRA such as that carried out by authoritative organizations, the process involves the extrapolation of toxicological data from studies conducted on laboratory animals considering the limited accessibility of epidemiological data. For nanoparticles in the air it means the normalization of the pulmonary burdens related to the adverse effects on animals so that the equivalent human pulmonary burden can be estimated from the information about the exposure of staff. (Kuempel et al., 2006; Kuempel et al., 2012b)

Employers are responsible for risk management; however, they often need counselling from appropriate authorities regarding suitable risk management procedures. The general instructions recommend informing the authorities about where there are nanomaterials and if possible performing exposure control as a preventive measure. Preventive instructions emerged from the use of the proposed and current regulations related to nanomaterials, for example for producers to show their risk management plans related to carbon nanotubes based on the Significant New Use Rules (SNUR) to the United States Environmental Protection Agency (EPA) within TSCA (EPA, 2013). Besides that, the effort for the development of the voluntary consensus standards for safe treatment of nanomaterials in the workplace (e.g. ISO TC 229)

Safety Engineering Series, ISSN 1805-3238 pp. 25-37, DOI 10.35182/tses-2019-0009

was an early example of responsible development (ISO, 2009). It is the responsibility of employers to use the best instructions available as the basis for exposure control in the workplace (including the instructors) and employees are responsible for cooperation with employers when carrying out risk management processes.

In these early decades of commercial nanotechnology there are a lot of examples which show that the principles and procedures of responsible development are widely supported (Tomellini and Giordani, 2008; NNI, 2011; Forloni, 2012; BIAC, 2013). However, it is not clear to what extent the preventive instructions are followed. This needs to be assessed on a national and global level. Preliminary research was a good start but it reflects a low rate of answers and potential bias of the volunteers (Engeman et al., 2012). To minimize these distortions, a stricter and more detailed evaluation is necessary. There are plans being prepared for making such evaluations. However, they are very expensive and it will also be difficult to identify companies which treat nanomaterials and get access to 'the workplaces. (Schulte and Iavicoli, 2012; Federal Register, 2013). Businesses, the government, and other organizations must invest in the development and coordination of these evaluations.

A critical criterion of responsible development of nanotechnologies is assessing the extent to which there is conformity with the preventive instructions about the protection of staff dealing with nanomaterials. Besides that, after carrying out this assessment, it will be important to identify hot spots, i.e. sectors, sub-branches and types of facilities or companies in which compliance with the regulations is less than suitable and then start rehabilitation and strategic intervention (e.g. information campaigns).

Last but not least, it is important to mention a principle which is currently strongly promoted. It is the Safe-By-Design concept, which covers the whole life cycle of nanomaterials and also affects the area of OHS. Namely in the 3rd pillar, which focuses on safe conditions at the place where nanomaterials are produced, so called Safe industrial production. The aim is to gain sufficient knowledge and tools for risk assessment in relation to the safe industrial production and especially safety in the workplace. In this pillar, the focus is on professional training of staff regarding occupational safety and health. It is an important supplementary step and at the same time support for the previous pillars in ensuring the overall safety of nanomaterials (Micheletti et al., 2018).

Approaches of risk management in workplaces containing nanomaterials

In relation to risk management in the workplace and establishing the overall OSH policy of specific entities, it is therefore possible to use the recommended procedures for managing these risks in the workplace. Probabilistic and deterministic approaches are generally applied in risk management, where the aim is to identify, analyse, evaluate and reduce the extent of risk using appropriate measures. As some professional studies say (Fojtík et al, 2014; YAH et al., 2012; Hirst et al., 2013; Oberdöster et al., 2005), the standard control hierarchy aiming to eliminate hazard and reduce exposure should also be respected in connection with nanotechnologies, as Fig. 5 shows.

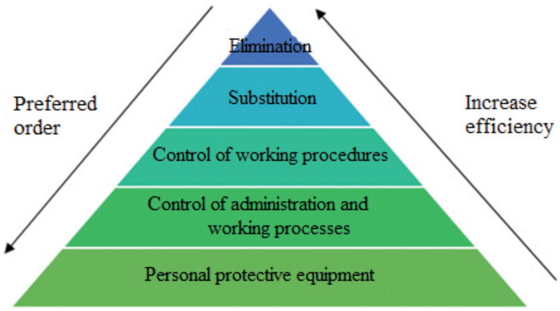

Fig. 5 Hierarchy of reducing the extent of risk in general (Roy et al., 2014)

The current recommended procedures in risk management, especially for nanoparticles, focus on the industrial area and processes, where there is occurrence of particles which originated as either primary or secondary products including non-productive processes. The approaches include:

- CENARIOS Risk Management - it is based on three principles which include hazard and risk assessment in relation to a product and process, so called 360° system of risk monitoring (estimating the relevant trends in research and development, focusing on regulation and technologies), management, and communication. (RMN, 2017)
- Control Banding - a qualitative and semi-quantitative approach focusing on the management of health and safety risk which generally consists of a scoring system for the hazard level of nanoparticles/nanomaterials and the level of exposure classified by defined parameters. Currently, the CB approach is implemented through the ISO/TS 12901-2:2014 standard as a preliminary technical standard of ČSN P CEN ISO/TS 27687 Nanotechnology (part 1 - terminology and definitions, part 2 - applying

Safety Engineering Series, ISSN 1805-3238 pp. 25-37, DOI 10.35182/tses-2019-0009

the CB approach). The CB approach is currently widely used in methods used for risk assessment such as CB Nanotool, Stoffenmanager Nano, ANSES Nano, NanoSafer, Swiss precautionary matrix. (NIOSH, 2013)

- EDF-DuPont NanoRisk Framework - based on six basic steps (material and application, life cycle, risk assessment, assessment of risk management, decision about risk, checking and adapting conditions), which are evaluated one by one and provide relevant information about risk. (U.S. EPA, 2012)
- 10-step risk management model - a qualitative approach based on logically divided basic steps - basic knowledge of the work process, risk assessment, identification of nanoparticles, identification of associated hazard, gaining the latest information, evaluation of the ways of exposure, risk identification, taking measures, documenting the whole process, another assessment of risks and the way of their management. (U.S. EPA, 2012)
- Precautionary Risk Management - based on four basic steps of risk management among which there are technology control (removing potential risks - raw materials, production, processes, production equipment etc.), production control (preventing and limiting the sources of risk etc.), personal protective working tools (protection of the respiratory tract, protection of the body surface etc.), monitoring the work environment. (Gourdazi et al., 2013)

Selecting a suitable risk management system depends on the type, frequency, and number of the processes which take place in the particular environment and are related to potential risks in the area of nanotechnologies and nanoparticle exposure. Considering the accessibility of relevant information, a possible modification of the approaches mentioned is sometimes recommended for a specific environment (Simko et al., 2014). However, it is necessary to maintain the basic character of the approach and at the same time use the knowledge and experience of experts when making a modification. The above-mentioned managerial approaches primarily use qualitative and semi-quantitative assessment.

The impact of nanoparticles on the health of staff

In connection with the rapid development of technologies more and more focus is placed on research into the effects of nanoparticles on human health (Fig. 6). The toxic effect of inhaled nanoparticles has been proved many times in the last years, however, there is still discussion concerning the exact mechanism of this impact on living organisms. (Bundschuh et al., 2018; Pandey and Prajapati, 2018; Roy et al., 2014)

What are generally considered the main causes of the toxicity of inhaled nanoparticles are their high surface reactivity and the related tendency to interact with cellular bio molecules, especially DNA and proteins. These interactions can provoke oxidative stress or inflammatory processes in a human body depending on the composition of the nanoparticles and their other physical-chemical properties (e.g. shape, charge), which may lead to further secondary effects in the tissues. (Bundschuh et al., 2018; Pandey and Prajapati, 2018; Roy et al., 2014)

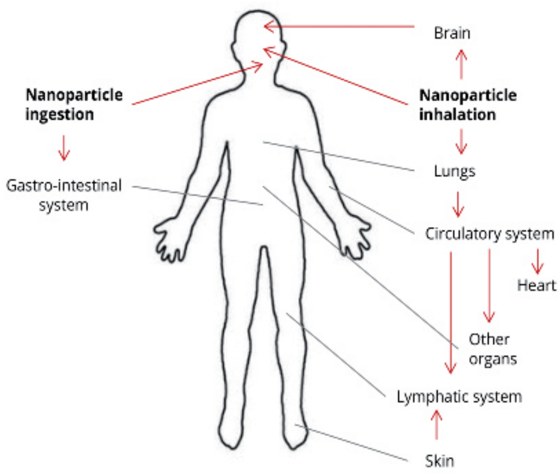

Fig. 6 Nanoparticle exposure (Buzea et al., 2007)

Depending on their composition, some nanoparticles may have a toxic impact on the human nervous system (Hu and Gao, 2010; Karmakar, et al., 2014). There are studies which monitored the connection between the concentration of nanoparticles and the mental state of persons directly in a particular work environment. Park et al. (2014) compared the results of 8 psychological tests taken by people working in a factory producing manganese alloys. In some of the psychological tests, the results of the persons who were exposed were statistically significantly worse. A similar study was later carried out by (Saenen et al., 2016) for children attending three primary schools in Belgium. They evaluated the connection between the results of 6 psychological tests and the concentration of nanoparticles to which the children are exposed at school and at home. They found statistically significant associations between some of the test results and both short-term and long-term exposure to nanoparticles. Based on a meta-analysis of

Safety Engineering Series, ISSN 1805-3238 pp. 25-37, DOI 10.35182/tses-2019-0009

31 studies, (Clifford et al., 2016) think that the present findings suggest that inhaled nanoparticles have a negative impact on the human cognitive functions, at least if they are affected during adolescence or late ageing. Like other authors (Peters et al., 2015; Clifford et al., 2016) also emphasise the necessity to carry out more longitudinal studies to acquire more detailed information about the effect of nanoparticles on the human cognitive functions.

The highest concentrations of nanoparticles are usually recorded in facilities where metals are treated under very high temperatures such as iron and steel works or welding shops (Viitanenet et al., 2017). In these facilities the concentrations recorded are up to a hundred times higher compared with the surrounding atmosphere. Working in such environment poses a significant health risk for the staff. People working in facilities using or producing nanomaterials which contain industrially produced nanoparticles may even be exposed to a higher risk (Pietroiusti and Magrini, 2014).

Monitoring nanoparticles in work environment for the purposes of risk assessment

For the reasons mentioned above, it is necessary to deal with nanoparticle exposure in work environment and monitor it. During model measurement it is important to characterize the source. It is necessary to consider leakage of nanoparticles during production or during the synthesis of nanomaterial, treatment or removal of nanomaterial in the form of powder, dispersion of substances containing nanoparticles (e.g. sprays), breaking or abrading products containing nanoparticles (e.g. grinding, cutting).

The next step is to evaluate the degree of transport from the source to the worker. For the ideal transport model we must consider variables such as the extent of nanoparticle coagulation mutually or with the surrounding environment and the extent of the disintegration of agglomerate into nanoparticles. The last step involves the characterization of the worker's exposure. The worker can be potentially exposed in two basic ways. One is direct inhalation and the other is exposure of the worker's digestive system and skin resulting from contact with the contaminated surface, where fallout or adsorption of nanoparticles occurred (e.g. work top, wall or the worker's clothes). (Schneider et al., 2011)

The Organization for Economic Co-operation and Development (OECD) recommends the following for monitoring nanoparticles in work environment (OECD, 2015):

- measuring before, during and after the process in which nanoparticles are treated in work environment;
- measuring simultaneously;
- measuring both during a real production process with nanoparticles and during the same empty process run without nanoparticles;
- measuring in the long term so that the trends in nanoparticle distribution can be statistically recorded;
- measuring both near the potential sources of nanoparticles and further from them in order to discover the sources statistically;
- measuring at a sufficient distance from the source causing air flow (e.g. ventilation).

Although there is still no suitable methodology in OSH for increasing safety when working with nanoparticles, it is necessary to take various measures. One of the options is isolation of the process or local ventilation. Myojo et al. monitored the leakage of nanoparticles in the production process. In the study they recorded 27 cases when isolation of the production process or local ventilation was used to eliminate the risks. They found that isolation of the production process provides practically complete protection while when there is only a ventilation system the percentage of the nanoparticles captured was approx. 90 % (Myojo et al., 2017).

Another option is the behaviour of the staff. The World Health Organization (WHO) think that the most effective way of nanoparticle risk elimination in work environment is the training of staff in the area of nanoparticle health risks and having them practise the procedures for their own protection. Apart from the training, using personal protective tools such as protective masks is also important (WHO, 2017).

The European Committee also recommends taking operational measures (EU, 2014):

- Reducing the number of staff who come into contact with nanoparticles.
- Reducing the time when the staff who come into contact with nanoparticles stay in the exposed space.
- Changing the current work procedures.
- Introducing stricter health procedures (HEPA filtration).

Safety Engineering Series, ISSN 1805-3238 pp. 25-37, DOI 10.35182/tses-2019-0009

Other possible negative effects of nanoparticle occurrence in the workplace

There are other complications connected with the potentially negative impact of nanoparticles on the health of staff which may be very important for employers. It is long-term incapacity of the staff. In fact, reducing the sickness rate is one of the main goals of every organization. The sickness rate has quite „deep roots" and affects many areas of a business management including OSH. The incapacity of an employee affects not only the area of accounting but also production. Incapacity can cause a reduction in productivity and therefore it is more difficult to achieve the targets. The economic impact connected with the absence of an employee because of illness includes primarily the wage compensation costs, the costs related to a substituting employee or paying for overtime. These costs can often reach up to 150 %. Managers know very well today how high the price is of an employee. An employee who leaves their job costs the company 18 monthly salaries on average. Shawn Achor, the author of *The Happiness Advantage*, says that happy employees have higher work productivity, produce higher sales and incapacity is much less likely for them. The studies (Gallagher, 2009) prove that happier employees are more precise and have better analytical abilities. Happier employees can cope with negative stress (Lyubomirsky, 2008), which, according to WHO, has fatal impact on the health of staff. Happier employees are more productive and hardly ever leave their jobs (Deloitte, 2014).

Conclusion

A lot of scientific studies have been published on the impact of nanotechnologies on human health especially in the recent years. However, an assessment of the studies analyzed above shows that the information about the risks related to nanotechnologies and nanoparticles is not sufficient. One of the reasons is that nanotechnologies have been used for rather a short time to such a great extent and the focus started to be placed on the potential risks only recently. If nanotechnologies are to avoid the kind of problems that afflicted the previous technologies emerging, it is necessary to define criteria for the responsible development of nanotechnologies. The cornerstone of responsible development is the obligation to protect the workers, who are the first people exposed to the potential risks of the technology. Another important aspect is the protection of the consumers and the environment but the basis of responsible development starts with the protection of the workers. This means that the risks identified and also those almost expected must be managed properly. Therefore, the culture of safety needs to be created, which will include measures valid for dusty environments and similar protective tools will be used for the work environment containing nanoparticles and the working modes used will be based on the principle that exposure to nanoparticles is possible only for a necessary period of time.

Acknowledgments

This paper is supported by TA ČR within the TL02000240 project of Increasing the Level of OSH Management in Workspace with Occurrence of Fine and Ultrafine particles.

References

Achor, S. 2011. The happiness advantage: the seven principles of positive psychology that fuel success and performance at work. New York: Broadway Books. ISBN 0307591549.

Aven, T. 2016. Risk assessment and risk management: Review of recent advances on their foundation. European Journal of Operational Research, 253(1): 1-13. ISSN 03772217.

Aven, T. 2017. How some types of risk assessment can support resilience analysis and management. Reliability Engineering & System Safety, 167: 536-543. ISSN 0951930.

Aven, T., Ylönen, M. 2018. A risk interpretation of sociotechnical safety perspectives. Reliability Engineering & System Safety, 175: 13-18. ISSN 0951930.

Business Industrial Advisory Committee to the OECD. Responsible development of nanotechnology turning vision into reality [online]. Biac.org, 2013 [cit. 2019-08-10]. Avavilable at: http://www.biac.org/news/2013/1303_BIAC_Vision_Paper_on_Nanotechnology.htm

Bonner, J. C., Rona, M. S., Alexia, J. T. et al. 2013. Interlaboratory Evaluation of Rodent Pulmonary Responses to Engineered Nanomaterials. The NIEHS Nano GO Consortium. Environmental Health Perspectives, 121(6): 676-682. ISSN 0091-6765.

Brouwer, D., Berges, M., Virgi, M., Fransman, W., Bello, D., Hodson, L., Gabriel, S., Tielsmans, E. 2012. Harmonization of Measurement Strategies for Exposure to Manufactured Nano-Objects; Report of a Workshop. The Annals of Occupational Hygiene, 56(1): 1-9. ISSN 1475-3162.

Buzea, Ch., Pacheco, I., Robbie, K. 2007. Nanomaterials and nanoparticles: Sources and toxicity. Biointer phases, 2(4): MR17-MR 71.

Bundschuh, M., Filser, J., Lüderwald, S. et al. 2018. Nanoparticles in the environment: where do we come from, where do we go to? Environmental Sciences Europe, 30(1): 6. ISSN 2190-4707.

Carayon, P., Hancock, P., Levenson, N. et al. 2015. Advancing a sociotechnical systems approach to workplace safety - developing the conceptual framework. Ergonomics, 58(4): 548-564. ISSN 1366-5847.

CENARIOS® - Managing Nano Risks: World's First Certifiable Risk Management and Monitoring System for Nanotechnologies [online]. Innovationsgesellschaft.ch, 2015 [cit. 2017-12-22]. Available at: http://innovationsgesellschaft.ch/wp-content/uploads/2015/01/CENARIOS_Factsheet_englisch_2015.pdf

Clifford, A., Lang, L., Chen, R., Anstey, K. J., Seaton, A. 2016. Exposure to air pollution and cognitive functioning across the life course - A systematic literature review. Environmental Research, 147: 383-398. ISSN 0013-9351.

Commission recommendation of 18 October 2011 on the definition of nanomaterial (2011/696/EU).

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.

Committee on improving risk analysis approaches used by the U.S. EPA. Science and Decisions: Advancing Risk Assessment. 2019. National Academies Press. DOI: 10.17226/12209. ISBN 9780309388146.

CSN IEC 300-3-9 01 0690: 1997. Dependability management - Part 3: Application guide - Section 9: Risk analysis of technological systems. Prague: Czech Standards Institute. (in Czech)

CSN EN OHSAS 18001: 2007. Occupational health and safety management systems - Guidelines for the implementation of OHSAS. Prague: Czech Standards Institute. (in Czech)

CSN EN OHSAS 45001: 2018. Occupational health and safety management systems - Requirements with guidance for use. Prague: Czech Standards Institute. (in Czech)

Global Human Capital Trend [online]. Deloitte.com, 2014 [cit. 2018-06-20]. Available at: https://www2.deloitte.com/insights/us/en/focus/human-capital-trends/2014.html

Eastlake, A., Hodson, L., Geraci, Ch., Crawford, C. 2012. A critical evaluation of material safety data sheets (MSDSs) for engineered nanomaterials. Journal of Chemical Health and Safety, 19(5): 1-8. ISSN 18715532.

Engeman, C. D., Baumgartner, L., Carr, B. M., Fish, A. M., Meyerhofer, J. D. et al. 2012. Governance implications of nanomaterials companies' inconsistent risk perceptions and safety practices. Journal of Nanoparticle Research, 14(3). ISSN 1388-0764.

EU-OSHA, 2018. Psychological risks and stress at work [online]. Osha.europa.eu, 2018 [cit. 2018-06-07]. Available at: https://osha.europa.eu/en/themes/psychosocial-risks-and-stress

European Commission, 2014. Working Safely with Manufactured Nanomaterials Guidance for Workers [online]. Available at: http://ec.europa.eu/social/BlobServlet?docId=13088&langId=en

Fojtík, A. et al. 2014. Nano - a fascinating phenomenon of the present: nanoparticles, nanostructures and nanotechnologies - sophisticated forms of matter: from the discovery of the phenomenon to biomedical applications. Prague [i.e. Dobrany]: COMTES FHT. ISBN 978-80-260-7135-8. (in Czech)

Forloni, G. 2012. Responsible nanotechnology development. Journal of Nanoparticle Research, 14(8). DOI: 10.1007/s11051-012-1007-1. ISSN 1388-0764.

Gallagher, M. W., Lopez, S. J., Preacher, K. J. 2009. The Hierarchical Structure of Well-Being. Journal of Personality, 77 (4): 1025-1050. ISSN 1467-6494.

Ghahramani, A. 2017. Diagnosis of poor safety culture as a major shortcoming in OHSAS 18001-certified companies. Ind health, 55(2). DOI 10.2486/indhealth.2015-0205.

Safety Engineering Series, ISSN 1805-3238 pp. 25-37, DOI 10.35182/tses-2019-0009

Gibson, R., Stacey, N., Drais, E., Wallin, H., Zatorski, W., Virpi, V. 2012. Risk perception and risk communication with regard to nanomaterials in the workplace. Luxembourg: Publications Office of the European Union, 118 p. ISBN 978-92-9191-738-9.

Goudarzi, S. et al. 2013. Nano technology risks: A 10-step risk management model in nanotechnology projects. Hypothesis, 11(1): e5. DOI:10.5779/hypothesis.v11i1.330.

Houtman, I. et al. 2008. New forms of physical and psychosocial health risks at work, study. EMPL, 122 p. IP/A/EMPL/ST/2007-19.

Hu, Y.-L., Gao, J.-Q. 2010. Potential neurotoxicity of nanoparticles. International Journal of Pharmaceutics, 394(1-2): 115-121. ISSN 0378-5173.

ISO Technical Committee 229 Nanotechnologies: 2005. Seattle: International Organization for Standardization.

Jonsen, A. 1991. Ethical considerations and responsibilities when communicating health risk information. Journal of Clinical Epidemiology, 44: 69-72. ISSN 08954356.

Karmakar, A., Zhang, Q., Zhang, Y. 2014. Neurotoxicity of nanoscale materials. Journal of Food and Drug Analysis, 22(1): 147-160. ISSN 1021-9498.

Kuempel, E. D., Tran, C. L., Castranova, V., Bailer, A. J. 2006. Lung Dosimetry and Risk Assessment of Nanoparticles: Evaluating and Extending Current Models in Rats and Humans. Inhalation Toxicology, 18(10): 717-724. ISSN 0895-8378.

Lee, J. H., Kuk, W. K., Kwon, M., Lee, J. H., Lee, K.S., Yu, I. J. 2012. Evaluation of information in nanomaterial safety data sheets and development of international standard for guidance on preparation of nanomaterial safety data sheets. Nanotoxicology, 7(3): 338-345. ISSN 1743-5390.

Lyubomirsky, S. 2008. The how of happiness: a new approach to getting the life you want. New York: Penguin Books. ISBN 9780143114956.

Makoto, E., Gamo, M., Honda, K. 2017. A review of toxicity studies on graphene-based nanomaterials in laboratory animals. Regulatory Toxicology and Pharmacology, 85: 7-24. ISSN 0273-2300.

Mička, V., Ježo, E., Lach, K. et al. 2015. Occupational exposure to airbone ultrafine particles in various industrial workplace. Transactions of the VSB - Technical University of Ostrava, Safety Engineering Series. VSB - Technical University of Ostrava, 1(10): 1-7. ISSN 1801-1764.

Micheletti, CH. et al. NANoREG's Safe by Design Concept for Nanomaterials [online]. Susnano, 2018. [cit. 2019-08-07]. Available at: http://www.susnano.org/images/SNO-SUN15/5A.2_Micheletti%20C%20_%20NANoREG's%20Safe-by-Desing%20concept.pdf

Mohammadfam, I., Kamalinia, M., Momeni, M. et al. 2017. Evaluation of the Quality of Occupational Health and Safety Management Systems Based on Key Performance Indicators in Certified Organizations. Safety and Health at Work, 8(2): 156-161. ISSN 2093-7911.

Myojo, T., Nagata, T., Verbeek, J. 2017. The Effectiveness of Specific Risk Mitigation Techniques Used in the Production and Handling of Manufactured Nanomaterials: Systematic Review. J UOEH, 39: 187-199. ISSN 0387-821X.

Nel, A., Tian, X., Huan, M., Xiang, W., Sijie, L., Zhaoxia, J., Haiyuan, Z. 2013. Nanomaterial Toxicity Testing in the 21st Century: Use of a Predictive Toxicological Approach and High-Throughput Screening. Accounts of Chemical Research, 46(3): 607-621. ISSN 0001-4842.

NIOSH, 2009. Notification on precautionary measures for prevention of exposures to nanomaterials. Japan NIOSH Notification No. 0331013. Japan: Labour Standard Bureau, Ministry of Health, Labour and Welfare.

NIOSH, 2013. Current Strategies for Engineering Controls in Nanomaterial Production and Downstream Handling Processes, Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH): Cincinnati, OH:U.S.

National nanotechnology initiative strategic plan [online]. National nanotechnology initiative, 2011 [cit. 2019-07-05]. Available at: http://www.nano.gov/node/581

OECD, 2015. Harmonized tiered approach to measure and assess the potential exposure to airborne emissions of engineered nano-objects and their agglomerates and aggregates at workplaces.

Ostraat, M. L., Thornburg, J. W., Malloy, Q. J. 2013. Measurement Strategies of Airborne Nanomaterials. Environmental Engineering Science, 30(3): 126-132. ISSN 1092-8758.

Pandey, R. K., Prajapati, V. K. 2018. Molecular and immunological toxic effects of nanoparticles. International Journal of Biological Macromolecules, 107: 1278-1293. ISSN 0141-8130.

Park, R. M., Bouchard, M. F., Baldwin, M., Bowler, R., Mergler, D. 2014. Respiratory manganese particle size, time-course and neurobehavioral outcomes in workers at a manganese alloy production plant. NeuroToxicology, 45: 276-284. ISSN 0161-813X.

Peters, R., Peters, J., Booth, A., Mudway, I. 2015. Is air pollution associated with increased risk of cognitive decline? A systematic review. Age and Ageing, 44(5): 755-760. ISSN 1468-2834.

Philbrick, M. 2010. An Anticipatory Governance Approach to Carbon Nanotubes. Risk Analysis, 30(11): 1708-1722. ISSN 02724332.

Pietroiusti, A., Magrini, A. 2014. Engineered nanoparticles at the workplace: current knowledge about workers' risk. Occupational Medicine, 64(5): 319-330. ISSN 0962-7480.

Ramachandran, G., Ostraat, M., Evans, D. E. et al. 2011. A Strategy for Assessing Workplace Exposures to Nanomaterials. Journal of Occupational and Environmental Hygiene, 8(11): 673-685. DOI: 10.1080/15459624.2011.623223. ISSN 1545-9624.

Risk management of nanomaterials: Guidelines for the Sftoxicoloafe Manufacture and Use of Nanomaterials [online]. RMN, 2017 [cit. 2017-12-17]. Available at: http://www.sun-fp7.eu/ wp-content/uploads/2017/01/SUN-risk-management-guidelines.pdf

Roy, R., Kumar, S., Tripathi, A., Das, M., Dwivedi, P. D. 2014. Interactive threats of nanoparticles to the biological system. Immunology Letters, 158(1-2): 79-87. ISSN 0165-2478.

Saenen, N. D., Provost, E. B., Viaene, M. K. et al. 2016. Recent versus chronic exposure to particulate matter air pollution in association with neurobehavioral performance in a panel study of primary schoolchildren. Environment International, 95: 112-119. ISSN 0160-4120.

An evaluation of MSDS and labels associated with the use of engineered nanomaterials [online]. Safe Work Australia, 2010. [cit. 2019-07-07]. Available at: http://www.safeworkaustralia.gov.au/sites/swa/about/publications/pages/rp201006evaluationofmsdsandlabels. Accessed 14 Aug 2013

Savolainen, K. 2012. Responsive development of nanotechnology. Barents Newsletter on Occupational Health and Safety, 15:33-35. ISSN 1455-8459.

Senčík, J., Nechvátal, M., Klouda, K. et al. 2016. Certified methodology for providing personal protective equipment in an environment with risk of nanoparticles [online]. Occupational Safety Research Institute [cit. 2018-06-11]. Available at: https://www.mpsv.cz/documents/20142/225499/Metodika_pro_poskytovani_OOP_v_prostredi_s_rizikem_vyskytu_nanocastic.pdf/260c679b-9a39-4734-12cd-79736892d095 (in Czech)

Sheehan, C., Donohue, R., Shea, T. et al. 2016. Leading and lagging indicators of occupational health and safety: The moderating role of safety leadership. Accident Analysis and Prevention. Elsevier, 1607 (92): 130-138. ISSN 0001-4575.

Schneider, T., Brouwer, D. H., Koponen, I. K., Jensen, K. A., Fransman, W., Van Duuren-Stuurman, B., Van Tongeren, M., Tielemans, E. 2011. Conceptual model for assessment of inhalation exposure to manufactured nanoparticles. J Expo Sci Environ Epidemiol, 21: 450-463. ISSN 1559-0631.

Schulte, P. A., Iavicoli, I. 2012. Nanotechnology. International Commission on Occupational Health (ICOH) Newsletter, Paulo, 10: 8-9.

Schulte, P. A., Ringen, K. 1984. Notification of workers at high risk: an emerging public health problem. American Journal of Public Health, 74(5): 485-491. ISSN 0090-0036.

Schulte, P. A., Geraci, C. L., Murashov, V. et al. 2014. Occupational safety and health criteria for responsible development of nanotechnology. Journal of Nanoparticle Research, 16(1).

Schulte, P. A., Kuempel, E. D., Zumwalde, R. D. et al. 2012. Focused actions to protect carbon nanotube workers. American Journal of Industrial Medicine, 55(5): 395-411.

Simkó, M., Nosske, D., Kreyling, W. G. 2014. Metrics, Dose, and Dose Concept: The Need for a Proper Dose Concept in the Risk Assessment of Nanoparticles. International Journal of Environmental Research and Public Health, 11: 4026-4048. ISSN 1660-4601.

Skřehot, P., Rupová, M. 2011. Nanosafety. Prague: Occupational Safety Research Institute, 240 p. ISBN 978-80-86973-89-0. (in Czech)

Ratio of nanotechnology patents to nano-articles (patents per 100 articles) [online]. StatNano, 2018 [cit. 2019-09-09]. Available at: https://statnano.com/report/s88

Stone, V., Pozzi-Mucelli, S., Schberger, K., Sabella, S., Vogel, U. B. et al. 2017. Research prioritisation to deliver an intelligent testing strategy for the human and environmental safety of Nanomaterials. EU-FP7.

Tomellini, R., Giordani, J. 2008. Third International Dialogue on Responsible Research and Development of Nanotechnology. Brussels: European Commission.

U.S. EPA, 2012. Approaches for assessing and controlling workplace releases and exposures to new and existing nanomaterials, in Internal Ceb Interim Draft.

U.S. EPA, 2013. Significant new use rules on certain chemical substances. 40 CFR Parts 9 and 721. RIN 2070-AB27. Direct Rule. Federal Register, 78: (152).

Van der Merwe, D., Pickrell, J. A. 2018. Toxicity of Nanomaterials. Veterinary Toxicology, 3rd ed. Academic Press, 319-326. ISBN 978-0-12-811410-0.

Viitanen, A.-K., Uuksulainen, S., Koivisto, A. J., Hämeri, K., Kauppinen, T. 2017. Workplace Measurements of Ultrafine Particles—A Literature Review. Annals of Work Exposures and Health, 61(7): 749-758. ISSN 23987308.

WHO, 2017. WHO guidelines on protecting workers from potential risks of manufactured nanomaterials.

WHO, 2018. Psychological risk factors and hazards [online]. WHO [cit. 2018-06-10]. Available at: http://www.who.int/occupational_health/topics/risks_psychosocial/en/

Zink, K. J. 2005. From industrial safety to corporate health management. Ergonomics, 48(5): 534-546. ISSN 1366-5847.

ZSBOZP, 2018. Psychological factors. Mental stress - risk identification and assessment [online]. Prague: Occupational Safety Research Institute [cit. 2018-06-04]. Available at: https://zsbozp.vubp.cz/pracovni-prostredi/rizikove-faktory/psychologicke-faktory/409-psychicka-zatez (in Czech)