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# Evaluation of exposure to aerosols at metallurgical plant workplaces

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### Hodnocení expozice aerosolům na pracovištích hutních provozů

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nanočástice aerosoly hutnictví pracovní ovzduší terénní testy prevence rizik

**Abstract**

The impact of aerosols on human health is increasingly discussed in the recent years. However, the firm assessment of the health risk due to exposure to aerosols is hindered by a lack of sufficient supporting data. Because the highest levels to aerosols are likely to be encountered in workplaces, protection of health of exposed workers by implementation of adequate protective measures is a priority. The research in this area includes identification of sources of exposure, exposure assessment, detailed characterization of the aerosol materials and biological effects thereof as well as the development of appropriate protective measures. A program of screening measurements and evaluation of protective measures at selected workplaces was recently launched by the Occupational Safety Research Institute (VÚBP) in Prague. In this paper, an example of the aerosol exposure assessment in a metallurgical plant as well as its interpretation is presented. Based on both the experimental findings and critical analysis of the current knowledge it is concluded that the presence of aerosols in workplace air is an important issue of occupational safety and health, deserving systematic attention and qualified management.

**Keywords:** working atmosphere, risk prevention, aerosol, nanoparticles, field measurements

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**Abstrakt**

Již delší dobu je v nejrůznějších rovinách pohledu diskutován vliv aerosolů na lidské zdraví. Nejnověji se pak tento fenomén rozrostl také o úvahy o možném negativním vlivu ultrajemných částic a nanočástic. Jsou však uváděné obavy důvodné? Nejsou uvažovaná rizika poněkud přeceňována? Na tyto otázky není možné v dnešní době zcela jasně odpovědět. Stále totiž chybí znalosti o toxických vlastnostech nanočástic tvořených nejrůznějšími materiály a nejsou k dispozici důkladné epidemiologické studie jejich vlivu na exponovanou populaci. Provádět posouzení zdravotních rizik v souvislosti s expozicí uvedeným materiálům například na pracovištích je tak stále hudbou budoucnosti. Zkušenosti z minulosti nás však na mnoha případech poučily, že existují-li pochybnosti, není radno možnou hrozbu podceňovat. Dvojnásob to platí u profesionální expozice na pracovištích, kde jsou lidé vystavováni zvýšeným koncentracím nejrůznějších polutantů a jejich směsím, aniž by si to často uvědomovali. Jelikož se toto téma stalo jistým „fenoménem doby“, rozhodl se Výzkumný ústav bezpečnosti práce, v.v.i., provést screeningové měření kontaminace ovzduší částicemi aerosolů na několika vybraných pracovištích. Smyslem této práce bylo nejen získat dílčí údaje o znečištění pracovního ovzduší ve vybraných průmyslových provozech, ale především provést analýzu současného přístupu v aplikaci preventivních opatření, která se mnohdy míjejí účinkům.

**Klíčová slova:** pracovní ovzduší, prevence rizik, aerosol, nanočástice, terénní měření

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## Introduction

The impact of aerosols on human health has been recently discussed from various points of view. However, the amount and quality of information needed to allow reliable assessment of the risk to health caused by the action of aerosols is not sufficient yet. Despite considerable progress in the field of research on this issue there are still numerous questions associated with toxic effect of very small particles and their entry into the organism. Considering the current status of knowledge, the European Scientific Platform NEW OSH ERA defined in 2009 two basic priorities of further research in the field of “nano security“: (1) development of methods for estimating exposure to aerosols and nanoparticles in working environment and (2) assessment of the risk to human health due to the above exposures. Among other significant objectives of priority research can be included also development of procedures for their detection and monitoring in working environment and recording changes in the health status of exposed individuals [6].

To contribute to the above program at a national level, the Occupational Safety Research Institute (VÚBP) in Prague has undertaken a series of screening measurements of working environment contamination at selected workplaces within the research project “*Work comfort and human reliability in a working system*“ as a part of the VÚBP´s research program no. MPS0002595001, with the following aims:

- to assess the level of contamination of working environment in selected industrial plants and to implement measures to reduce health risks especially due to long-term occupational exposures;
- to develop an optimal procedure of datamining for qualitative and quantitative evaluation of aerosol exposure at workplaces;
- to evaluate the possibility of further application of the ICRP model (see below) in practice.

In this paper we report on our study to assess exposure to aerosols in a metallurgical plant in the Czech Republic.

## Exposure to aerosols and methods of its evaluation

Aerosols (systems consisting of particles with the size ranging from small clusters of molecules up to 100 micrometers, dispersed in the air) are ubiquitous component of every natural or indoor environment. All organisms including man have adapted to the presence of atmospheric aerosols during the whole lifetime. Except their living environment people are exposed to aerosols also in their working environment where unusual or unique pollutants can be encountered [1]. The aerosols particles penetrate into the human body mostly by respiratory way, to a lesser extent across the skin and also, with food, into digestive tract [4]. Then they interact with the body and may cause various adverse effects. The type and magnitude of these effects depends on the particles´ characteristics such as their size, distribution, amount (i.e., mass concentration), chemical composition, presence of other substances on their surfaces etc. The exposure to occupational aerosols may also show great variability in time. Thus, due to a large number of relevant variables of small particles (including nanoparticles), limited knowledge on their toxicological properties, and variability in the exposure scenarios, assessment of the health risk associated with occupational exposures to aerosols presents a very complex task [8].

Based on the previous experience and knowledge there are no doubts that exposure to aerosols and nanoparticles can affect the human health adversely. This has been confirmed by various studies dealing with the health effects of cigarette smoke, a mixture consisting of organic compounds and particles of approximate size of 100 nanometres. During 1920s a lot of people started smoking cigarettes. Two decades later an increase of lung cancer incidence was observed. In 1940s rose the number of smoking women and increasing incidence of lung cancer of women was observed in 1960s. Therefore it is surprising that the fight with smoking has started to be more energetic only in recent years. For example, the British government had solid information on the relationship between smoking and lung cancer already in 1956, but for fear of financial losses due to lower tax collection it concealed information from the public [2]. The role of aerosol particles in the overall effect of cigarette smoke is not completely known but it is considered to be significant. Another example of airborne particles adversely effecting human health is asbestos, which has been a very popular and widely used multipurpose material for a long time. The work with asbestos was completely prohibited by the law and any manipulation with it (for example for research purposes or at the disposal of existing products) has been strictly regulated since 1990s when carcinogenic effect of asbestos was clearly demonstrated.

Evaluation of health effects of very small particles is a very complex task that cannot be fully attained at the current level of knowledge. On the other hand, assessment of exposure to these particles is more feasible. The dose absorbed in the body via inhalation route can be assessed using suitable models, of which that implemented by International Commission of Radiological Protection (ICRP) is generally recognized. The ICRP model is valid for breathing through the nose. It consists of several equations for calculating the fractions of deposited particles of various sizes in the major regions (alveolar, tracheobronchial and upper airways) of human respiratory system. Using this partial data also the total deposition of aerosol in the whole human respiratory system can be calculated. The model is valid for monodisperse airborne spherical particles of standard density in the size range from 0.001 to 100 μm [3], and can be very well used in the working environments with not severely fluctuating conditions. It has an advantage to allow exposure assessment without the need of having large amount of data. The sufficient data is mass concentration of the size fractions over the whole range of measurement. To assess deposition in the alveolar and tracheobronchial regions, the measurement of representation less than 35 μm particles is sufficient. Those measurements can be performed by Grimm 1.10X (X = model range 6 to 9) that are quite widespread in our country. Using the concentration data over the defined size fractions we can calculate the exposure dose absorbed during a defined time period (a shift, a year) provided that we know the exposure scenario during the work shift, physical load of the job, personal protective equipment used, etc. Physical load affects the workers´ respiratory volume (l/min) which is used to calculate the total volume of inhaled air over a period of exposure.

The ICRP model is considered to be an approximate model in that it doesn´t consider clearance from or chemical interaction of the deposited material in human body. In spite of that it is a useful tool that may significantly contribute to the exposure assessment needed for a qualified decision on the preventive measures [7].

## Measurement of aerosols at the workplace

The measurement at the workplace was carried out to obtain the most representative data in terms of location and timing of the employees´ exposure. The measuring devices were placed at a level of breathing zone of the adult person, i.e. 1,6 m above the floor (Fig. 1). The device used for the measurement was Grimm 1.109 (Grimm Aerosol Technik, Germany) (see picture 1). The size fractions monitored were PM1, PM4, PM10, and 32 particular size fractions of particles with an aerodynamic diameter in the range of 0.22 to 32 μm.

**Fig. 1: Measurements in the metallurgical plant**

That measuring device used was particle counters based on laser photometry (nephelometry). The air is drawn into them by a pump at a constant flow rate of 1.7 l/min. The aerosol particles with aerodynamic diameter larger than the monitored size group (1-10 μm) are separated by the impactor attached at the entry of the measuring device. The principle of the impactor consists in trapping the larger particles on the impactor walls due to their higher inertia, i.e., the reduced ability to be carried by the air flow. Only the smaller particles pass into the analytical part of the device, which is an optical detector of laser light scattered on the particles. Intensity of the scattered light is used to calculate the mass concentration of the particles. The Grimm 1.109 device is used to monitor the aerosol particles at the aerodynamic diameter from 0.25 to 32 μm and mass concentration from 0.0001 to 100 mg/m$^3$. It is calibrated using polystyrene latex spheres (PSL) standard on the differential mobility (DMA) analyzer and condensation particle counter (CPC). The adjusted results were recalculated to mass concentrations of the major aerosol fractions present at the workplace. Integration time of devices was set to 1 min, reflecting 1-min means of mass concentration of selected size fractions calculated from the individual values collected in 10-s intervals. A big advantage of this type of measurement is the possibility to monitor even the fast concentration fluctuations occurring in the course of the work shift. This output therefore enables to identify the work operations producing significant aerosol emissions, which can be used to reduce the risk effectively. In addition to monitoring aerosol particles, microclimatic parameters (temperature, relative air humidity and air velocity) were measured using a Testo 445 device to complete the description of situation at the workplace.

## Results

Aerosol present at workplace air of a metallurgical plant was characterized using a Grimm 1.109 particle counter to determine mass concentration of 32 size fractions over the range of 0.2 to 32 µm. Fig. 2 (blue columns) shows that mass concentrations in the size fractions from 0.2 um to ca. 4 um were at a very similar level (ca. 1000 ug/m$^3$), while the mass concentrations in fractions larger than 4 um were successively decreasing. This primary data was then put into the ICRP model to assess the total inhaled and alveolar doses of the above size fractions during a one-year exposure. The plot of total inhaled doses (mg/year) along the size fractions has a shape of a peak, with doses about 2000 mg in the smallest particle fractions, increasing to about 12 000 mg in the fractions around 3 µm, and then decreasing fast in the large particle fractions (Fig. 2, red columns). On the other hand, the plot of alveolar doses (mg/year) along the size fractions is rather flat, with doses about 1000 mg in the smallest particle fractions, increasing to about 1800 mg in the fractions around 2 µm, and then decreasing fast in the larger particle fractions (Fig. 2, while columns). Thus, Fig. 2 demonstrates usefulness of the ICRP model to identify size distribution and doses of physiologically relevant aerosol particles deposited in the exposed subjects, allowing the optimal workplace prevention measures to be taken.

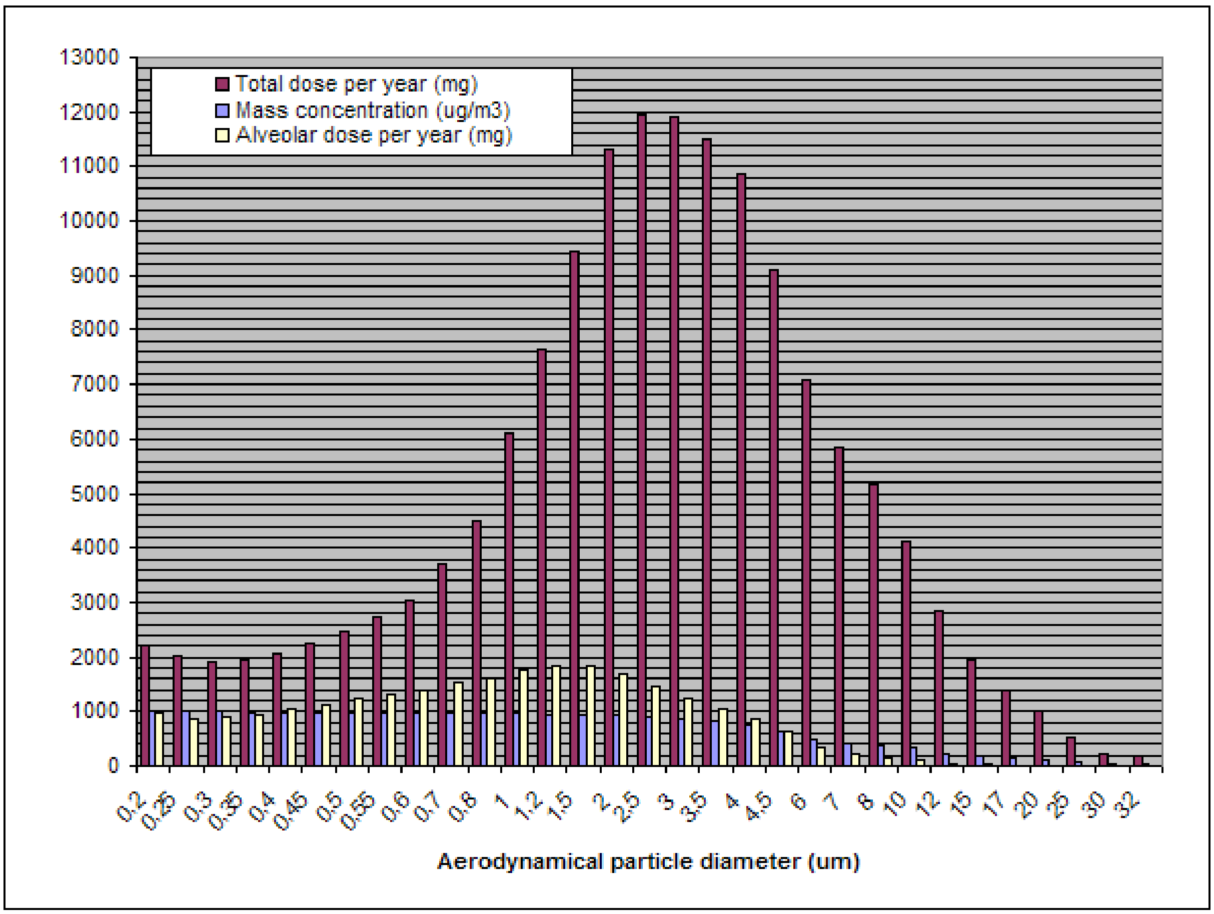


**Fig. 2: Estimated doses of individual aerosol size fractions (between 0.2 and 32 µm) deposited in whole respiratory system (red columns) and in alveolar region (white columns) of a worker exposed to aerosol in a metallurgical plant for 1 year. The mass concentrations of the above particle size fractions are depicted by blue columns**

## Discussion

Our study was carried out at 20 workplaces to find out the current state of contamination of working environment with aerosols as well as the preventive measures implemented. The aerosol particles measurement and characterization at these workplaces are not reported in this paper except that presented in results. However, the current state of preventive measures at workplaces deserves a comment. Our investigations showed that the protection of employees at a satisfactory level was implemented only in some production units visited. The reason is that employers don´t have sufficient information on aerosol characteristics at their workplaces which may result in low efficiency of the implemented measures. As an example, the employer only knows the total aerosol mass concentration as, requested for workplaces ranked in category 2R and higher according to notice no. 432/2003. But the employer totally misses the information about size distribution of the aerosol particles (as shown for example in Fig. 2). Therefore it can happen very easily that the employees are provided a certain type of filter half masks which are not able to trap the particles of certain size effectively. The biggest problem in this situation can occur with particles smaller than 0.3 µm. These may represent predominant fraction of the total and alveolar doses at some workplaces in spite of that the trapping efficiency of filter material in their half masks can be as low as 70% [3,8].

The undertaken measurements enabled to develop the scheme of whole shift measurement of aerosol exposure using the above devices as well as to interpret the results qualitatively and quantitatively in an appropriate manner. It also confirmed usefulness of the ICPR model for the purposes of exposure assessment in working environment. However, the assessment of exposures to aerosol particles smaller than 0.2 µm would require different monitoring methods.

Our study also indicates that aerosols in working environment represent a chronically underestimated issue and that the adopted protective measures often don´t reflect properties of the given aerosol. In general, the employers are encouraged to make use of the real in site measurements when designing the most effective protection of employees´ health instead of relying on recommendations provided by producers of the personal protective devices.

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