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Occupational exposure parameters for characterization of nanoparticulate matter toxicity: Metal versus wood processing

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ABSTRACT

Three environments were chosen for this study (office, metal, and woodworking industries). The results obtained by an electrical low-pressure impactor (ELPI+) in this study show that the particle number concentration and surface area are significantly higher in workplaces of the metal- and wood-working industries but concentrations of mass are lower. Therefore, the characteristics of mass should not be used on their own as a representative parameter for the description of occupational exposure and cannot be used for occupational risk assessment as a single parameter. The nanoparticles ratio together with occupational exposure limits could possibly be used as the background for occupational risk assessment. At the same time, it is essential to mention that the nanoparticle ratio alone is insufficient and parameters like concentration levels, chemical composition, and shape characterization must also be taken into account, especially in occupational toxicology studies done in the future. According to the SEM data, samples from the metal industry contained more ultramicroscopic and nanometric particles (e.g. toxic metals such as Zn, Mn, and Cr) and fewer microscopic dust particles.

1. Introduction

People face various degrees of exposure to nanoparticles—both natural and caused by human activity (engineered and non-engineered nanoparticles)—on a daily basis. However, there is still a lack of both theoretical and practical understanding of the impact of nanoparticles on human health and possible mechanisms of their interaction with biological objects. Recent developments in the use of nanotechnology and discussions about it in the scientific community have resulted in the new science of nanotoxicology, specializing in research on nanodevices and nanostructures in living organisms (Sellers et al., 2009). Some countries have also started to develop special regulations and risk assessment methodologies, including Russia (Estokova and Stevulova, 2012). In order to determine the potential risks and safe levels of human exposure to nanoparticles, it is necessary to develop reliable methodologies for the identification of potential hazards.

There is special concern with regard to the assessment of human-generated nanoparticles in various occupational settings in order to understand possible toxicity to the

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human body using available information on nanoparticles like the number, surface area, mass, chemical composition, shape, and so on (O'Shaughnessy, 2013; Peixe et al., 2015).

It has been stated that the number and surface area of nanoparticles are more important for occupational toxicity assessment of inhaled nanoparticles than their mass concentration and that their chemical composition also plays an important role (Young et al., 2013; Koponen et al., 2011; Ramachandran et al., 2011; Heitbrink et al., 2009; Donaldson et al., 2005; Oberdörster et al., 2005; Gomez Yepes and Cremades, 2001). Apart from the characteristics of nanoparticles, the work tasks, sampling distance from the source, air velocity, engineered control, and prevention measures as well as the background levels of various particles also have a significant influence on the concentrations of airborne particles (Boowook et al., 2013; Zhang et al., 2013; Rylander and Jacobs, 1994). A recent extensive review by LaGrega et al. (2010) (with almost 200 references) raised discussion on the interactions of synthesized nanomaterials with the biological systems of the human body (tissues, intracellular, etc.). This review mostly emphasized the effects of nanoparticles of metal oxides (TiO_2, ZnO, ZrO_2, CeO_2, SiO_2, and functionalized SiO_2) and two carbon nanomaterials (multiwalled carbon nanotubes and carbon black) and also brought some new results (LaGrega et al., 2010). The authors' focus was on analysing the exposure levels and possible pathways of nanoparticles in the body as well as biophysical modifications of surfaces and agglomeration in cell cultures. Also the toxicity of nanoparticles both *in vitro* (cell viability, genotoxicity, and inflammation) and *in vivo* was analysed while trying to rank potentially hazardous materials. According to the researchers, the main entrance route of nanoparticles regardless of their parameters is via inhalation (Peixe et al., 2015; LaGrega et al., 2010).

The mucosal epithelium lining the upper and lower airways provides an efficient barrier against inhaled particles (e.g. dust particles, biological agents, and so on) but bulk flow combined with particle motion leads to sedimentation of inhaled particles at alveolar level. Alveolar deposition models show peak particle deposition at sizes of 30 and 4000 nm but minimal particle deposition at 50 μm. Particles may be deposited on the basement membrane or may enter the lymphatic stream or bloodstream. Macrophages take up the majority of particles but they are inefficient in taking up particles in the range of 15–80 nm that are located in epithelial cells or interstitial space. It also has to be considered that soluble compounds (also containing nanosized particles) are generally rapidly absorbed (Nelson et al., 2010).

Current research shows that the greatest hazards in occupational settings are caused by biologically stable nanoparticles, so it will be of crucial importance to understand and evaluate their toxicity by thorough investigation of the effects on human health of nanoscale particles at system and cellular level (LaGrega et al., 2010). This could then lead to the development of reliable occupational risk assessment methodologies in future and could also help in the planning of efficient technological control and prevention measures (O'Shaughnessy, 2013; LaGrega et al., 2010; Maynard and Kuempel, 2005). Taking into account all these aspects, this study aimed at a practical evaluation of nanoparticle distribution in various workplaces and analysis of the nanoparticles' chemical composition and possible adverse health effects due to the alveolar deposition of the nanoparticles, thereby their potential further penetration into epithelial cells.

2. Methodology

Three different environments (three case studies) were chosen in order to perform pilot measurements for this study: an office environment (without printing and copying processes) to assess the background level (level without nanoparticles generated by human activity during work processes) and distribution of nanoparticles; the metalworking industry to assess the processes involving welding (shielded metal arc welding) and grinding, which emit a significant amount of particles at the nanoscale range (<100 nm), and the woodworking industry to assess particles of mainly biological origin. The surroundings of all three enterprises were similar: they were located in a city but away from the main streets and major roads. All workplaces were equipped with ventilation systems (exhaust and supply) and in the cases of the metal and wood industries also with local exhaust ventilation.

Real-time measurement data from one working shift (8 h including breaks) were collected by electrical low-pressure impactor (ELPI+, Dekati Ltd, Finland). Measurements were performed approximately 1.5 m from the floor and as close to the worker as technically possible (1–2 m from the operator as the ELPI+ measuring device limited closer access to the breathing zone of the operator as the instrument is not intended for personal sampling). The particles were collected by electrical low-pressure impactor (ELPI+, Dekati Ltd, Finland) on aluminium (Al) substrate foils for SEM (scanning electron microscopy with a Nova NanoSEM 650) analyses and a 14-stage cascade impactor was used for air quality measurements to measure the particle size distribution, number, surface area, and mass.

The impactor classified particles on the so-called stages (stage 1 to stage 14) into 14 fractions by size in the range from 6 nm to 10 μm (the characteristics of each stage are shown in Table 1) with a 9.87-lpm sample flow rate using an outlet pressure of 40 mbar and an inlet pressure of 1013.3 mbar. The data were saved every second. All ELPI+ measurement files were transferred to Excel spreadsheets, where all calculations were done. In this study, we used the total number, surface area, and mass concentration by size and also calculated nanoparticles' number, surface area, and mass ratio (percentage of the total particle number concentration) for nanoparticles from stage 1 to stage 5. Boowook et al. (2013) used the nanoparticle ratio to describe the occupational exposure of nanoparticles, too.

Particles of different size fractions from stages 2 to 14 (particles from stage 1 were not analysed as it was technically not possible to collect particles of this size on Al foils) were collected on 25-mm Al foils.

Energy-dispersive X-ray analysis (EDX, the attachment to high-resolution SEM) was used to provide the elemental analysis or chemical characterization of the dust particles in a low-vacuum field-free mode operating at a potential of 15 kV spot 3.0. The technique used provided quantitative and spatial analyses of the distribution of chemical elements through mapping (two to three parallel measurements) and point analysis (four to five parallel measurements).

The particles from stage 2 to stage 8 were fixed on carbon PELCO tabs using the Al foils but those from stage 9 to stage 15 were collected and fixed on carbon tabs directly (without Al foils) due to their lightweight characteristics and instability.