A good practice guide for safe work with nanoparticles: the Quebec Approach

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Abstract: new industrial revolution has already begun around nanotechnologies, letting us anticipate major scientific breakthroughs that will affect each economic activity sector and whose expected global economic impacts will exceed $1000 billion annually by 2012. Simultaneously, many studies reveal that nanoparticles represent different occupational health and safety (OHS) risks unique to them and that often differ from the risks related to the same chemical substances with larger dimensions. As the number of potentially exposed workers increases and much uncertainty persists about OHS risks, this extended abstract proposes a framework for occupational risk management with the objective of controlling exposure to NPs in a context of a major lack of specific data related to the hazards of these substances and to the level of occupational exposure. The framework takes into consideration the equal representation of both the employers and workers in the Québec legislation and accounts the potential routes of exposure and focuses on a structured approach dealing with hazard identification, exposure characterization, risk assessment and risk management through different control methodologies. These are included in a prevention program that must be followed up, once it has been implemented, and refined through an iterative approach as new data become available.

1. Introduction

The interest of nanotechnology (NT) is based on the fact that many specific properties of nanoparticles (NPs) exist only at their small size (<100 nm). On the one hand, the incorporation of these NPs into NT-based products could substantially improve their performances, promote economic development, improve the quality of life, and contribute to the protection and rehabilitation of the environment [1]. On the other hand, the development of new products through research, their industrial synthesis and the incorporation of these new particles into various products, processes, and workplaces raise important health and safety concerns since some workers could be exposed to these NPs through inhalation, skin absorption or ingestion, during synthesis, packing, storage, shipping, transportation, spills, etc [1-3]. This is of particular interest since many expert groups or research organizations have already completed reviews of the scientific literature and identified various potential risks related to engineered NPs [1-10]. Specific data on hazards are still extremely limited. There are many uncertainties as to what extent the unique properties of engineered nanomaterials, which underpin their commercial potential, pose specific occupational health risks. Among these uncertainties, the
actual difficulty of determining which metric of exposure (mass, surface area, number of particles...) is best related to toxicity and the complexity of evaluating the occupational exposure are also contributing to the challenge of establishing quantitative risk assessment. Another concern with NPs relates to their very high specific surface area per unit of mass, with some highly reactive or easily oxidizable NPs possibly posing a threat of uncontrolled reactions, explosions and fires.

With such uncertainties and the increasing number of workers potentially exposed to NPs, it becomes essential that safe work practices be developed, implemented and validated in research laboratories and industrial plants. This extended abstract proposes an approach to hazard identification; to exposure, toxicological and risk assessment; and to risk management in the specific context of limited information. These data will constitute the basis for the implementation of a prevention program in research laboratories and in industrial workplaces.

2. Risk Assessment

Risk assessment is based on the hazard (toxicity or safety) that can cause harm and the probability that it happens (level of exposure). The risk associated to the toxicity is associated with the inherent toxicity of the material, the magnitude and duration of the exposure, the persistence of the material in the body and, for a specific worker, that person’s susceptibility or health status. The toxicity is usually well correlated to the absorbed mass of the substance. Studies with NPs clearly show that the measured biological effects are not well correlated to the mass of the NPs absorbed, but instead to other parameters such as the specific surface area, the number of particles, the size, the granulometric size distribution, the surface reactivity or the chemical composition, and the solubility of the NPs [3-5, 9-12]. There is actually no international consensus on the metric or metrics that best correlate effects and doses. In addition, most studies conclude that, at equal mass, NPs are more toxic than larger particles of the same chemical composition. Important uncertainties arise because of gaps in knowledge about the factors that are essential for predicting health risks. These factors include routes of exposure, translocation of materials once they enter the body, and interaction of the materials with the body’s biological systems [3-7, 9-14].

With a very high specific surface area per unit of mass and under specific conditions, some chemically-reactive or combustible NPs could have a potential for catalytic reactions, fires or explosions. Although insufficient information exists to predict these physical risks associated with NPs, nanoscale combustible materials might present a higher risk than coarser materials of similar composition and quantity. Decreasing the particle size of combustible materials could reduce the minimum ignition energy and increase the combustion rate [1, 13, 15, 16]. The dustiness of the NPs, dust explosiveness, and the minimum ignition energy and ignition temperature are essential parameters for the characterization of the safety-relevant aspects of dusts. Some industrial processes and manipulations could create conditions that could promote explosion or fire: confinement, concentration of combustible NPs in the air within the limits of explosivity, sufficient concentration of oxygen, and an ignition source. Inadequate ventilation, spills, leaks, or poor housekeeping using inappropriate methods are examples of situations that could promote the formation of NP clouds, and increase the probability of explosions and exposure of workers, mainly through inhalation [1, 14-16].

It is apparent from the above discussion that parameters such as the specific surface area, number of particles, size distribution and composition are essential for measuring exposures to nanoscale materials [1, 13, 17, 18]. Many instruments can be used to document exposure: mass concentration (cascade impactors, piezoelectric microbalances, tapered element oscillating microbalance, electrical low pressure impactor (ELPI), scanning mobility particle sizer (SMPS)); surface area (diffusion charger, direct-reading instruments, SMPS, transmission electron microscopy (TEM)); number concentrations (condensation particle counter, electrometers, SMPS, ELPI, scanning electron microscopy (SEM), TEM); granulometric distribution (SMPS, differential electrical mobility sizer, cascade impactors, ELPI, SEM, TEM), chemical composition (laboratory techniques, TEM, SEM). One important factor is that the evaluation of all these parameters in the worker’s breathing zone is actually impossible. In
fact, specific detection of NPs is actually a challenge because natural and anthropomorphic nano-sized particles are already present in the ambient air. The sensitivity and specificity of existing instruments could also be insufficient since low concentrations are expected in many environments, and most existing instruments are cumbersome, nonspecific, expensive and difficult to use in workplaces. Despite the actual limitations of the available instrumentation, it seems essential to document the workers’ exposure by measuring a maximum of parameters that could be correlated to adverse health effects or safety risks. The mass concentration should also be evaluated as it is the only parameter that can often be used to compare results to previously available data [1, 13, 17, 19].

Quantitative risk assessment normally relies on the availability of exposure limits based on dose-response relationships and the quantitative evaluation of the exposure. The risk assessment then triggers the risk management measures to be implemented [20, 21]. In the case of NPs, neither the toxic effects (or the safety hazards) nor the exposure level can be quantified, thus leading to major uncertainties in risk assessment (Figure 1). In the absence of data for utilizing traditional quantitative risk assessment methods to quantify the risk, expert judgments can be used.

![Figure 1: Risk assessment of nanoparticles results in uncertainties](image)

3. Risk management and prevention program

In such a situation of multiple uncertainties, the authors recommend that a risk management program be implemented through an iterative prevention program (Figure 2) that includes a regular reassessment of available hazard and exposure information [22]. A precautionary approach should be adopted until the risk can be quantified and managed. Control banding could be extremely useful as it helps to identify the level of prevention to implement [22]. The right two columns of that Figure 2 detail different items to take into account during the implementation step.

The Québec legislation is based on the assumption that an essential condition for the successful implementation of a prevention program is the employer’s strong leadership and commitment, and total employee involvement [1, 22]. When these essential conditions are in place, the next step is to interpret all the existing information (nature of NPs; hazards; phase (solid, suspension…); processes, equipment and volumes involved; flow of material; sources of potential exposure; worker’s position relative to airstreams and emission source; movement of workers (tasks, activities); work methods; sites of potential leaks and emission; handling; transportation; storage; housekeeping; ventilation;
equipment maintenance/decontamination; prevention measures; emergency procedures; exposure data, etc. Based on this information, decisions are made on how to control these risks at an acceptable level, and action is taken.

Figure 2. Proposed prevention program applicable to nanoparticles detailing major elements of the implementation step

Due to the many uncertainties in the case of NPs, the expert’s judgment becomes a critical element in risk management. The OHS prevention program should be an integral part of the risk management program and it should also be integrated into the overall management of the organization [1, 13, 16, 21, 22]. Each step of the program is essential. Nevertheless, with the uncertainties related to NPs, all the elements of this program should be continuously reviewed in an iterative process as new data become available. The classical hierarchy of controls should be efficient against NPs. Our experience in workplace interventions suggests that one of the key elements in optimizing the impact of the prevention program is related to the validation of the efficiency of the prevention measures and to the maintenance of the prevention equipment. The use of respirators should be limited to cases where all the other prevention measures do not succeed in controlling the concentration of NPs in the air at the desired level, or during specific high-risk exposure operations (equipment maintenance, emergency...
following spillages and accidental releases. Because the health impacts of worker exposure to NPs are not known, it could be useful to implement biological monitoring and medical surveillance, whenever possible, but this approach is extremely limited as little information is available at this time to define the appropriate parameters of biological monitoring. Medical screening and surveillance could be useful for identifying health problems that might be linked to NP absorption.

4. Conclusion

Nanotechnology is a rapidly developing but the different hazards associated with NPs are only partially known and the level of air contamination is difficult to relate to a significant metric. In most situations, the risks cannot be quantified. Nevertheless, the development and implementation of an efficient prevention program is possible despite the many uncertainties related to NPs.

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