Guidelines for Safe Handling, Use and Disposal of Nanoparticles

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Abstract. Health, safety and environmental (HSE) risks of a technology is an inseparable part of it which threatens all exposed employees. It has been proved for many years that exposure to particles, in an occupational setting, could be linked with the onset of lung diseases, such as pneumoconiosis, chronic obstructive pulmonary disease (COPD), and mesothelioma and lung cancer. Nanoparticles, due to their unique characteristics including; small size, shape, high surface area, charge, chemical properties, solubility, and degree of agglomeration can cross cell boundaries or pass directly from the lungs into the blood stream and ultimately reach to all of the organs in the body. This is the reason why they may pose higher risk than the same mass and material of larger particles. Moreover, biodegradation of nanoparticles by some kinds of fungi (like wood decay fungi) may result in metabolites which may be toxic to microorganisms under aerobic and anaerobic conditions. Bacteria and living cells can take up nanoparticles, providing the basis for potential bioaccumulation in the food chain. Considering Iran's prominent position in nanotechnologies and fast-growing in research and industrial activities, controlling nanoparticles related HSE risks should be highly considered. In general, there are three main approaches to risk and exposure control: engineering techniques, administrative means and personal protective equipments. These complementary approaches especially engineering techniques should be considered starting with the design stage of an industrial process. Administrative means of control constitute an additional approach when the other methods have not achieved the expected control levels. Administrative means of control must never substitute for engineering techniques, which always be performed according to standard practices. In some situations, due to insufficiently advanced technology and prohibitive costs,
engineering measures can not be implemented. In these situations, performing administrative means of control constitute other ways of limiting the occupational exposure risks. Accordingly, to minimize the risks from known and unknown health, safety and environment hazards in research and occupational settings of the country, guideline for safe handling, use and disposal of nanoparticles has provided.

1. Introduction

Nanotechnology is defined as: research and technology development at the atomic, molecular, or macromolecular levels using a length scale of approximately one to one hundred nanometers in any dimension; the creation and use of structures, devices and systems that have novel properties and functions because of their small size; and the ability to control or manipulate matter on an atomic scale [1]. For biomedical application, this definition has been expanded to include particles greater than 100 nm, such as liposomes, in order to encompass particle sizes that take advantage of anatomical considerations, such as vascular gaps surrounding tumours [4]. Nanotechnologies, allow us to build new materials, atom by atom. This often endows the materials with properties that are very different from ordinary materials. At the nano level, the behaviour of particles is dominated by quantal effects. The particles may be confined to a small structure, distributed over large surfaces or demonstrate an entire series of unique phenomena and properties not encountered in larger materials [2].

The field of nanotechnology is advancing rapidly and will likely revolutionize a broad range of consumer, medical, and industrial sectors. As with any new technology, we are faced with many unknowns; all of which raise questions concerning occupational safety and health. Nanotechnology also has the potential to improve the environment, both through direct applications of nanomaterials to detect, prevent, and remove pollutants, as well as indirectly by using nanotechnology to design cleaner industrial processes and create environmentally responsible products. However, there are unanswered questions about the impacts of nanomaterials and nanoproducts on human health and the environment [1].

Currently, a broad range of processes have been influenced by nanotechnology which will pose likely higher exposure potential to workforces in the nanotechnology occupational settings than consumers of final products. Considering inadequate information, until the results from research studies can fully elucidate the characteristics of nanoparticles that may potentially pose a health risk, precautionary measures are warranted [7, 8]. Concerning Iran's prominent position in nanotechnologies and fast-growing in research and industrial activities, minimizing the risks from known and unknown health, safety and environment hazards of handling, use and disposal of nanoparticles in nanotechnology workplaces (research laboratories and industrial firms) is considered as a priority. To fulfil the main objective, a document titled "Guideline for Safe Handling, Use and Disposal of Nanoparticles" has been issued to address the potential health, safety and environment hazards of nanomaterials and available good practices for mitigating the risks. This guideline will help the decision makers to:

- develop site-specific controls that will protect workers and the environment,
- offer reasonable guidance for managing the uncertainty associated with nanomaterials whose hazards have not been determined and reducing to an acceptable level the risk of worker injury, worker ill-health and negative environmental impacts and
- promote consistency in policy and procedures between the nanotechnology workplaces.

During reviewing literatures, it was identified, among the 30 industrialized countries of the organization for economic co-operation and development (OECD), that United States, England, Germany, European commission and Australia have developed good practices documents in the safety of manufactured nanomaterials [13]. Following the review of the documents, this paper attempts to address briefly the good practices which could be suitable and effective in reducing the risks.
2. Nanomaterials potential health, safety and environmental hazards

Potential routes of nanoparticle exposure include inhalation, dermal, oral, and in the case of biomedical applications, parenteral (Figure 1) [4]. Uptakes of nanoparticles by inhalation or ingestion are likely to be the major route in terrestrial organisms [3, 5, 10]. Discrete nanoparticles are deposited in the lungs to a greater extent than larger respirable particles and deposition increases with exercise due to increase in breathing rate and change from nasal to mouth breathing and among persons with existing lung diseases or conditions. These nanoparticles may also enter the bloodstream from the lungs and translocate to other organs like brain [3, 6, 8, 9, 10]. This is the reason why they may pose higher risk than the same mass and material of larger particles.

According to the researches no particle with an aerodynamic diameter of 1 nm, or 0.001 micrometre, reaches the alveoli, while 80% are deposited in the nose and pharynx. The other 20% are deposited in the tracheobronchial region. At this size, retention of inhaled nanoparticles is nearly 100% [2, 6]. For particles larger than 5 nm, deposition is predominantly in the alveolar region of the lungs. The deposition fraction of inhaled nanoparticles is greater in the alveolar and tracheo-bronchial regions of human lungs, compared to the larger-diameter inhaled particles. Once deposited, nanoparticles may also remain in the lungs longer than larger particles, due to decreased clearance and increased retention of nanoparticles. Particle deposition in these regions may be important in the development of airways diseases, such as chronic obstructive pulmonary disease (COPD) or asthma [6]. Studies also support a direct role for inhaled nanoparticles in systemic disease, such as cardiovascular disease. For example, CNTs have been shown to induce platelet aggregation in vitro and enhance thrombosis in vivo [4].

Since the late 1980s, toxicological evidence has been emerging indicating that the health effects associated with inhaling nanoaerosols may not be closely associated with particle mass. However, current research indicates that particle size, surface area, and surface chemistry (or activity) may be more important metrics than mass and bulk chemistry [6, 7, 9]. The toxicity and health risk of nanoparticles may also be a factor of the properties like agglomeration state, size distribution, shape, biopersistence/durability/solubility, porosity, physical properties, crystal structure/crystallinity and trace impurities/contaminants [7].

There is some evidence that dermal exposure to nanoparticles may lead to direct penetration of nanoparticles into the epidermis and possibly beyond into the blood stream [3, 9, 11, 25]. However, at this time, it is not known if skin penetration of nanoparticles would result in adverse effects as these studies have not been reported in animal models [3]. The limited in vivo studies that have been conducted to address the issue of cutaneous toxicity have identified only mild irritation as an adverse response to topical nanomaterial application. Nanoscale metal oxides, for example, are currently used in commercially available sunscreens, and have undergone extensive animal and clinical testing to fulfil regulatory requirements. These studies found minimal irritancy potential, and no evidence of photo-irritation, sensitization, or photo-sensitization [4]. In contrast, some recent studies have revealed some cutaneous penetration by ultrafine beryllium particles and the formation of cutaneous nodules [2].

Ingestion is another route whereby nanoparticles may enter the body. Ingested particles smaller than 20 µm (20 000 nm) can pass through the intestinal barrier and enter the bloodstream. Ingestion can occur from unintentional hand to mouth transfer of materials and direct ingestion of contaminated drinking water or particles absorbed on vegetables or other foodstuffs [2, 3, 5]. Ingestion may also accompany inhalation exposure because particles that are cleared from the respiratory tract via the
mucociliary escalator may be swallowed [3, 8]. Little is known about possible adverse effects from the ingestion of nanoparticles.

Although insufficient information exists to predict the fire and explosion risk associated with nanoparticles, the general trend is for the violence of the dust explosion and the ease of ignition to increase as the particle size decreases or specific area increases. Decreasing the particle size of combustible materials can reduce minimum ignition energy and increase combustion potential and combustion rate, leading to the possibility of relatively inert materials becoming highly combustible. Depending on their composition and structure, some nanomaterials may initiate catalytic reactions and increase their fire and explosion potential that would not otherwise be anticipated from their chemical composition alone [2, 3, 8, 12].

Moreover, nanomaterials released to soil can be strongly sorbed to soil due to their high surface areas and therefore be immobile. Bacteria and living cells can take up nanosized particles, providing the basis for potential bioaccumulation in the food chain. Certain nanomaterials are being designed for release as reactants in the environment, and therefore are expected to undergo chemical transformation. One example of this is iron (Fe0). Biodegradation of nanoparticles by some kinds of fungi (like wood decay fungi) may result in metabolites which may be toxic to microorganisms under aerobic and anaerobic conditions [1].

3. Exposure assessment

Particle sampling and measurement is extremely helpful in understanding exposure and risk in workplace scenarios [8]. In general, personal sampling is preferred to ensure an accurate representation of the worker’s exposure, whereas area samples (e.g., size-fractionated aerosol samples) and real-time (direct-reading) exposure measurements may be more useful for evaluating the need for improvement of engineering controls and work practices. Several of the instruments and techniques like condensation particle counters (CPC), Electron microscopic analysis (SEM and TEM), Scanning or Stepped Mobility Particle Sizer (SMPS), Electrical Low Pressure Impactor (ELPI), Diffusion Charger and Tapered Element Oscillating Microbalance (TEOM) are readily available to measure or estimate directly or indirectly different metrics as mass, number and surface area of nanoparticles [2, 3, 6, 7, 8, 11, 28]. Regardless of the metric and method selected for exposure monitoring, it is critical that measurements must be conducted before production or processing of a nanomaterial to obtain background exposure data [3, 7, 11]. Currently, there is not one sampling method that can be used to characterize exposure to nanosized aerosols. Therefore, any attempt to characterize workplace exposure to nanoparticles must involve a multifaceted approach incorporating many of the sampling techniques mentioned above, all relevant characteristics of nanoparticle exposure being measured.

By using a combination of these techniques, an assessment of worker exposure to nanoparticles can be conducted. This approach will allow a determination of the presence and identification of nanoparticles and the characterization of the important aerosol metrics. However, since this approach relies primarily on static or area sampling some uncertainty will exist in estimating worker exposures [3, 6, 7, 8]. Of the three primary physical exposure metrics (mass, surface area and number), there is strong evidence to suggest that occupational nanoaerosols should be monitored with respect to surface area [2, 7].

4. Occupational Exposures

Few workplace measurement data exist on airborne exposure to nanoparticles that are purposely produced and not incidental to an industrial process. In general, it is likely that processes generating nanomaterials in the gas phase, or using or producing nanomaterials as powders or slurries/suspensions/solutions (i.e. in liquid media) pose the greatest risk for releasing nanoparticles. In addition, maintenance on production systems (including cleaning and disposal of materials from dust collection systems) is likely to result in exposure to nanoparticles if it involves disturbing deposited nanomaterial. Exposures associated with waste streams containing nanomaterials may also occur [3]. Table 1 summarises the most common routes and potential sources of occupational exposure to a
nanomaterial [5, 7, 11]. Clean In Place (CIP) technologies may be used to eliminate the opening of process vessels and reduce the potential for unbound engineered nanoparticle (UNP) releases during cleaning operations. Minimization of maintenance activities by task planning (identification of required tools, replacement parts, etc) may help reduce exposure time by shortening maintenance times [7].

In processes involving high pressure (e.g. supercritical fluid techniques), or with high energy mechanical forces, exposures could occur in the case of failure of sealing of the reactor or the mills [10]. The potential for exposure to nanoparticles also exists when transferring nanomaterials within or outside the work area [7]. Factors affecting exposure to UNP include (a) the amount of material being used; (b) whether the material can be easily dispersed (in the case of a powder) or from airborne sprays or droplets (in the case of suspensions), or is fixed on or within a matrix (and generally do not present an exposure risk); (c) the degree of containment; (d) duration of use or presence in exposure areas; and (e) state of agglomeration or aggregation [7,14].

| Process Synthesis | Particle Formation | Exposure Source or Worker Activity | Primary Exposure Route |
|-------------------|-------------------|----------------------------------|-----------------------|
| Gas Phase         | In air            | Direct leakage from reactor, especially if the reactor is operated at positive pressure. | Inhalation |
|                   |                   | Product recovery from bag filters in reactors. | Inhalation / Dermal |
|                   |                   | Processing and packaging of dry powder. | Inhalation / Dermal |
|                   |                   | Equipment cleaning/maintenance (including reactor evacuation and spent filters). | Dermal (and inhalation during reactor evacuation) |
| Vapour Deposition | On substrate      | Product recovery from reactor / dry contamination of workplace. | Inhalation |
|                   |                   | Processing and packaging of dry powder. | Inhalation / Dermal |
|                   |                   | Equipment cleaning/maintenance (including reactor evacuation). | Dermal (and inhalation during reactor evacuation) |
| Colloidal         | Liquid suspension | If liquid suspension is processed into a powder, potential exposure during spray drying to create a powder, and the processing and packaging of the dry powder. | Inhalation / Dermal |
|                   |                   | Equipment cleaning/maintenance. | Dermal |
| Attrition         | Liquid suspension | If liquid suspension is processed into a powder, potential exposure during spray drying to create a powder, and the processing and packaging of the dry powder. | Dermal |
|                   |                   | Equipment cleaning/maintenance. | Dermal |

5. Transportation

All shipments of nanomaterials, regardless of whether they meet the definition for hazardous materials or not, should be consistently packaged using the equivalent of a DOT-certified Packing Group I (PG I) container. Any nanomaterial being shipped by air that meets the definition of dangerous goods according to the International Civil Aviation Organization (ICAO) must be packaged, marked, labelled, and shipped, with an accompanying properly prepared dangerous goods declaration, in accordance with the ICAO technical instructions. Therefore, nanomaterials must be packaged, marked, labelled, shipping papers prepared and shipped in accordance with 49 CFR 100 to 185. It should have a secondary seal, such as tape seal, or a wire tie to prevent a removable closure from inadvertently opening during transport. The outer package should be filled with shock absorbing material that can (a) Protect the inner sample container(s) from damage (b) Absorb liquids that might leak from the inner container(s) during normal events in transport [15, 16].
6. Nanomaterials spills
No specific guidance is currently available on cleaning up nanomaterial spills or contaminated surfaces. Available standard approaches to cleaning up powder and liquid spills include the use of HEPA-filtered vacuum cleaners, wetting powders down, using dampened cloths to wipe up powders and applying absorbent materials/liquid traps. Damp cleaning methods with soaps or cleaning oils is preferred [3, 7, 17]. To deal with spills and contaminated surfaces current good practices should be modified or new standard operation procedures (SOPs) provided. These should involve small (typically involving less than 5 mg/ml of material) of nanoparticle-containing powder or solutions and larger spills [18]. Using an absorbent walk-off mat where the clean-up personnel will exit the access controlled area, barriers to minimize air currents across the surface affected by the spill and providing safety equipments such as eyewash fountains, first aid kits, safety showers, multi-purpose fire extinguisher (ABC) and spill kits are also recommended [8, 15, 19].

Currently, portable peristaltic pumps are used by few organisations to transfer liquid to waste containers in order to prevent potential spills and reduce aerosolisation of the material. These pumps, because they work on positive displacement, are less prone to producing aerosols as opposed to conventional high pressure pumps [20].

7. Labelling
Currently, there is no generic labelling requirement for either manufactured nanoparticles (MNPs) and products containing manufactured nanoparticles (PCMNPs) used by both suppliers and users. Labelling and specifications are important tools for addressing possible adverse effects of nanomaterials on health and the environment. It is recommended that the term *nano* should only be used on a product label if the product does in fact contain manufactured nanoscale entities or produces a nano-enabled effect. Labelling is recommended for:

- MNPs,
- PCMNPs, except where the nanoparticle component of the product is intimately bound and could not be released under reasonable and foreseeable conditions of use or disposal,
- PCMNPs which are components of complex systems (e.g. a vehicle, mobile phone or game console), which could be expected to release MNPs under reasonable and foreseeable conditions of use or disposal,
- by-products, for which MNPs are generated as by-products.

Additional to that required by any legal obligation or known risks of the product, it is recommended that content of labels for PCMNPs or MNPs provide required information for consumer, professional and business-to-business uses. These information including a list of ingredients, technical specification, claims of intellectual property or indications of compliance with specific standards, instructions for handling, maintenance, cleaning, storage or disposal of the product, first aid or other medical treatment, name, address and contact details of the producer, identification data that can be used to trace the product and minimum professional competence. This should be advised in instructions and, wherever possible, on labels permanently attached to the product itself, or where that is impractical, on packaging in which the product is intended to be kept by the consumer. In the event that this is not possible, such information should be combined with accompanying instructions [21]. Figures 2 and 3 show minimum information appeared on inner packaging label for dry particulates and non-particulates.
8. Exposure Control Strategies

8.1. Engineering controls
Exposure to nanoparticles should be prevented, preferably by avoiding so far as is reasonably practicable the use of a hazardous substance by substituting a substance or process which eliminates or reduces the risks to health. If, however, this is not possible then exposure should be controlled by applying protection measures appropriate to the activity and consistent with the hierarchy of control [8]. Many harmful chemicals and processes are currently used as a matter of tradition although less harmful alternatives exist. Substitution of less harmful chemicals and processes for particularly hazardous ones has the advantage of completely removing a hazard from a workplace so that the potential for exposure is gone. Substitution is a complex process that requires research and experimentation. A secondary benefit of substitution can be reduction or elimination of waste and the costs associated with its disposal, regulatory compliance, liability, and environmental impact. It is important to compare the chemicals being considered for substitution not only for toxicity but also routes of entry, vapour pressure, flammability, particle size, safe disposal, etc. A slurry/brick/waxy material or a material encapsulated in a dissolvable plastic bag or gelatine capsule instead of a dry powder, flow coating or dipping instead of spraying, water blasting instead of abrasive blasting are some examples of possible substitutions [22]. Until more information become available, cautionary measures should be acted.

Consideration should be given to the following prudential limits when selecting analogous precautionary measures:
- measures should be consistent in scope and nature with comparable measures from comparable areas;
- measures should be proportional to the chosen level of protection and the scope of the harm (e.g., severity, irreversibility, uniqueness, numbers affected, temporal and spatial extent);
- measures should be chosen with due consideration of costs and benefits (cost effective);
- and measures (and underlying assumptions) should be continuously reviewed in light of new information and understanding [7].

For most processes and job tasks, the control of airborne exposure to nanoaerosols can be accomplished using a wide variety of engineering control techniques similar to those used in reducing exposure to general aerosols. Engineering control techniques such as source enclosure (i.e., isolating the generation source from the worker) and local exhaust ventilation systems should be effective for capturing airborne nanoparticles. Current knowledge indicates that a well-designed exhaust ventilation system with a high-efficiency particulate air (HEPA) filter should effectively remove nanoparticles [3, 7].

Employees may be isolated from hazardous operations, processes, equipment, or environments by distance, by physical separation, barriers, control rooms, isolation booths, closed systems or containers (e.g., sealed reactor vessels, closed storage containers or vessels, pumps enclosures, valve isolation, glove boxes) and by capture ventilation. As a further precaution, regulated areas can be established.
around enclosed operations with access only to a limited number of essential employees. Air locks with interlocked doors and computerized card readers and doors with alarms add an extra measure of isolation and prevent unauthorized entry [2, 7, 22]. According to an international survey, respondents were asked whether “nano-specific” facility design and engineering controls were used to safely manage worker exposure. Furthermore, respondents were asked whether the organization utilized cleanrooms, fume hoods, biological safety cabinets, laminar flow clean benches, glove boxes, glove bags, a closed piping system, pressure differentials (negative or positive), isolated heating, ventilation, and air conditioning (HVAC) systems, or other controls specifically for handling nanomaterials. Overall reports of engineering controls are reported in Figure 4.

![Figure 4. Reports of “nano-specific” facility design and engineering controls [23].](image)

Fume hoods were the most widely reported engineering control. The results of a similar survey, performed by Conti et al. indicated that again fume hoods had highest use compared to other engineering controls [27]. Fume hoods were used with a variety of materials and phases but the highest usage was among organizations that worked with solutions, which could be an indication that fume hoods were used more as a barrier of protection against harmful vapours than nanomaterials. Fume hoods were less likely to be used when the nanomaterial was in a dry powder form. This may have been due to the potential loss of dry powder form material and the risk of inhalation stemming from air turbulence generated by the fume hood exhaust system. Most reports of fume hood use were associated with the handling of nanopowders, carbon nanotubes, dispersions, and fullerenes. European and North American organizations reported the highest (82%, 72% respectively) and organizations from Asia reported the lowest (52%) use of fume hoods.

The survey results indicated that again North American and European organizations had the highest use of glove boxes in their nanomaterial operations (64% and 45% respectively) especially in working with nanopowders and carbon nanotubes. This result is in contrast to Asian countries, where only 36% reported using glove boxes. Those organizations working with colloidal dispersions were the least likely to report using a glove box. Nearly all organizations working with nanowires, nanocrystals and carbon black reported using glove boxes [23]. General ventilation is often ineffective and, in some situations, recirculation of a fraction of the air may be prohibited by the regulations in force [2, 22].

Nanoparticle behaviour varies greatly depending on the dimensions and degree of agglomeration. Airborne, non-agglomerated nanoparticles behave much like gases, thus allowing rapid diffusion over long distances. For this reason, the engineering control systems, such as enclosure and ventilation, must be designed according to the gaseous and particulate properties of the nanoparticles [2, 11, 24, 25]. Wet scrubbers or electrostatic precipitators in the final stage of filtration are recommended. This capture principle, involving electrostatic attraction, is particularly effective for very fine particles [2].

Biological safety cabinets (BSCs) are designed to protect the operator, the laboratory environment and work materials from exposure to infectious aerosols and splashes that may be generated when manipulating materials containing infectious agents, such as primary cultures, stocks and diagnostic specimens [26]. Based on the results of the previously mentioned survey higher instances of reported use of biological safety cabinets came from organizations working with a range of smaller amounts of nanomaterials at any given time. One organization indicated that their biological safety cabinet, type
2b2, did not recirculate air like conventional biological safety cabinets. The air was HEPA-filtered before being exhausted, thus preventing the emission of nanomaterials into the environment. While this type of cabinet was available commercially, it did not appear to be widely utilized for nanomaterial applications.

The cabinets were used by organizations working with a range of smaller amounts, particularly nanopowders in powder or suspended form or colloidal dispersions. North American organizations reported marginally higher use of this control compared to Asian or European organizations. In general, compared to North American organizations, Asian organizations used fewer “high–end” engineering controls. Some respondents stated that, when handling dry powders, fume hood exhaust fans would be “off” to prevent nanomaterials loss. That was an important finding because several other organizations reported using certain engineering controls less to protect workers from exposure than to prevent the loss of the nanomaterial or to protect the material from the ambient environment [23, 27].

8.2. Administrative controls

Administrative means of control constitute an additional approach when the other methods have not achieved the expected control levels. In these situations, reduction of work periods, modification of work practices, personal hygiene measures, housekeeping and preventive maintenance constitute other ways of limiting the occupational exposure risks [2, 3, 7]. As examples of good practices, handwashing, showering, changing and cleaning clothes facilities should be provided to prevent the inadvertent contamination of other areas (including take-home) caused by the transfer of nanoparticles on clothing and skin. The storage and consumption of food or beverages and smoking in workplaces should be prevented where nanomaterials are handled. Dry mopping, sweeping, dusting, cleaning using compressed air or portable blowers or fans are prohibited. Work areas should be cleaned at the end of each work shift (at a minimum) using either a HEPA-filtered vacuum cleaner or wet wiping methods [2, 3, 7, 15].

It is also recommended to prepare written operating procedures, sufficient operational training, to conduct regular and timely inspection of process, manufacturing, operational and exposure control equipment and ancillary systems (including ventilation and filtration equipment), and regular and timely preventative and corrective maintenance and repair of such equipment [7]. It is generally emphasized to keep the number of potentially exposed worker as small as possible. Lastly, routine monitoring and health and medical surveillance should be carried out as needed [7, 8]. Currently, no specific measurable health effects have been uniquely associated with exposure to nanomaterials (other than those already associated with larger variants of the same materials) [8].

The survey results generally revealed that organizations working with nanomaterials use conventional chemical safety methods through the life-cycle of nanomaterials [20, 27]. Concerning this, developing and implementing a chemical hygiene plan satisfying the criteria in 29 CFR 1910.1450 has been required in some nanomaterial laboratories [15, 18, 29]. At this time, improving existing related laws and regulations (particularly laws and regulations for chemicals) or developing really needed new ones should be highly considered. Regulations such as Registration, Evaluation and Authorisation of Chemicals (REACH) program in the European Union and the Toxic Substances Control Act (TSCA) and RCRA in the U.S have good capabilities to regulate nanosubstances. The existing regulatory network will be modified if necessary. Here are a few examples of regulations applicable to nanoparticles and nanostructures that could be modified [2].

8.3. Personal protective equipments (PPE)

Nanoparticle exposure may often be attributable to the wearing of inadequate PPE [18]. Protective clothing that would typically be required for a wet-chemistry laboratory would be appropriate and could include but not limited to:

- closed-toed shoes made of a low permeability material,
- long pants without cuffs, a long-sleeved shirt,
- gauntlet-type gloves or nitrile gloves with extended sleeves,
- chemical splash goggle and Laboratory coats [15, 18].

Standard tests showed that non-woven fabrics, like high density polyethylene textile (Tyvek type), seems to be much more efficient against nanoparticles penetrations. Thus, it is advised to avoid the use of protective clothing made with cotton fabrics [2, 30]. Diffusion tests performed with nanoparticles showed that nanoparticles may penetrate through commercially available gloves. The tests revealed that gloves material is not the only criteria, elaboration process and thickness are major issues as well. As a result of this, use of at least two layers of gloves is advised [15, 30].

The use of respirators is often required when engineering and administrative controls do not adequately keep worker exposures to an airborne contaminant below a regulatory limit or an internal control target [2, 3]. Based on the previous survey results, just a little over half, indicated that employees used respiratory protection when working with nanomaterials. It was also revealed that: respirators were used at 100% of organizations that stated they worked in the chemicals sector and 93% of those in nanomaterials manufacturing; respirators were used by only 50% of the other business categories [20]. Intermediate protection is assured by using a PAPR (powered air-purifying respirator) with adequate APF (Assigned Protection Factors), which includes high-efficiency filtration and a pump supplying a full-face mask. In cases where high-efficiency dust filters are insufficient, airline respirators or self-contained breathing apparatus are necessary [2, 7, 14, 15].

Currently, there are no specific exposure limits for airborne exposures to engineered nanoparticles (except 0.1 mg/m$^3$ for ultrafine particles of TiO$_2$) although occupational exposure limits and guidelines (e.g., OSHA, NIOSH, ACGIH) exist for larger particles of similar chemical composition. In determining the effectiveness of controls or the need for respirators, it would therefore be prudent to consider both the current exposure limits and guidelines (e.g., PELs, RELs, TLVs) and the increase in surface area of the nanoparticles relative to that of particles for which the exposure limits or guides were developed [3]. It is believed that P-100, FFP3 and P3 cartridge-type respirators or respirators provide higher level of protection than others [8, 15, 16, 24, 27, 28].

8.4. Waste disposal

As mentioned above, many organizations working with nanomaterials use conventional chemical safety methods through the life-cycle of nanomaterials. It is also obvious that regulation in Europe regarding nanoparticles is based on existing laws and regulations for chemicals [2]. Due to these, at this time many organizations characterize all nanomaterial wastes as potentially hazardous wastes and use related regulations to manage their wastes [8, 20, 31]. In the UK, the List Of Waste Regulations 2005 (LOWR) provides a list of hazardous properties, including examples, such as H5 “Harmful substances” and H6 “Toxic substances”. H5 would be a reasonable worst case assumption for many insoluble and soluble nanoparticle types but H6 would describe CMAR types (carcinogenetic, mutagenic, asthmagenic or a reproductive toxin) and would be a reasonable worst case assumption for carbon nanotubes or other nanomaterials having a fibrous nature [8].

In the U.S, subtitle C of RCRA covers the storage, transportation, treatment, disposal, and cleanup of hazardous wastes. Nanomaterials that meet one or more of the definitions of a hazardous waste (i.e., a waste that is specifically listed in the regulations and/or that exhibits a defining characteristic) potentially would be subject to subtitle C regulations. RCRA regulations set out several requirements for generators of hazardous wastes. Most notably, RCRA requirements for generators vary based on the amount of hazardous waste that they generate in a calendar year. Because nanoscale materials may present novel properties at comparatively small quantities, the current 100 kg annual threshold to qualify as a CESQG (conditionally exempt small quantity generators) may allow the on-site storage and management of nanomaterials for extensive periods of time. EPA may review whether to vary storage and management quantity thresholds based on the actual hazard posed by the nanomaterials rather than their quantity [32]. Moreover, nanoscale materials that meet the definition of “chemical substances” under the Toxic Substances Control Act (TSCA), but which are not on the TSCA Inventory, must be reported to EPA according to section 5(a) of the Act, which provides for pre-
manufacture review [1]. It is concluded that despite EPA’s sweeping powers to regulate hazardous waste management and its comprehensive regulatory framework, there are several areas of potential interest where EPA may wish to determine whether its current regulations will have unintended consequences when applied to nanoscale waste materials [32].

9. Conclusions
It has been currently known that some engineered nanomaterials will present new and unusual risks, but there is very little information on how these risks can be identified, assessed and controlled. In contrast, good occupational hygiene practices and existing knowledge on working with hazardous substances provide a useful basis for working safely with nanomaterials. But where existing knowledge fails, new research is needed to fill the gaps. Until more information become available nanomaterials should be considered as hazardous materials. Lastly, in the future, many types of nanoparticles may turn out to be of limited toxicity but precaution should be used until more is known.

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