Egyptian Journal of Occupational Medicine, 2015; 39 (2) : 195-212

NANOTECHNOLOGY IN OCCUPATIONAL MEDICINE REVIEW ARTICLE

By

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Abstract:

Preliminary researches indicate that in some cases nano-particulate matter may be more toxic than other forms of the same or similar material. The term prevention comprises all measures directed at minimizing the risk associated with a specific exposure, the early detection through medical surveillance of adverse health effects resulting from such an exposure and the treatment of diseases. Application of the classical tools of occupational medicine and industrial hygiene are hampered by the lack of consensus guidelines for medical monitoring, exposure assessment, and exposure control. So, the problem of occupational exposure to nanoparticles (NPs) has raised many questions which remain unanswered till today. This review aims at discussing some general features of ENMs (Engineered nano-materials), how a worker might be exposed to ENMs, some potential health effects, and approaches to minimize exposure and toxicity.

Key words: Nanotechnology- Nanoparticles- Engineered nanoparticles- Occupational health and safety.

What is Nanotechnology?

Nanotechnology is most generally defined as the intentional manipulation of matter to form novel structures with one or more dimension or features less than 100 nm. (Richard, 2009).

Applications of nanotechnology:

Nano-technology enhanced materials will enable a weight reduction accompanied by an increase in stability and improve functionality. Practical nanotechnology is essentially the increasing ability to manipulate (with precision) matter on previously impossible scales, presenting possibilities which many could never have imagined.

Nanotechnology is an emerging technology that can be used in a broad array including nano medicine which ranges from the medical applications of nanomaterials to nanoelectronic biosensors and even possible future applications of molecular nanotechnology. Nanotechnology projects related to energy are: storage, conversion, manufacturing improvements by reducing materials and process rates, energy saving and enhanced renewable energy sources. The applications of nanotechnology in commercial products include titanium dioxide (TiO_2) and zinc oxide nanoparticles in sunscreen, cosmetics and some food products; silver nanoparticles in food packaging, clothing, disinfectants and household appliances such as Silver Nano; carbon nanotubes for stain-resistant textiles; and cerium oxide as a fuel catalyst. Nanotechnology has the potential to make construction faster, cheaper, safer, and more varied. Automation of nanotechnology construction can allow for the creation of structures from advanced homes to massive skyscrapers much more quickly and at much lower cost. An inevitable use of nanotechnology will be in heavy industry. Lighter and stronger materials will be of immense use to aircraft and spacecraft manufacturers leading to increased performance (Richard, 2009).

Occupational Hazards due to manufactured nanoparticles:

Employees involved in the development, production, distribution and use of these nanoparticles are already potentially exposed to materials of uncertain toxicity. The challenge to occupational health professionals is

to prevent the development of disease in employees handling these novel nanomaterials despite the lack of toxicological information, consensus exposure standards air sampling methodologies and medical monitoring protocols. So, we have to know more about the pharmacokinetic and pharmacodynamics of nanoparticles inside the body.

Nanotoxicology is an emerging discipline that can be defined as science of engineered nanodevices and nanostructures that deals with their effects in living organisms.

Toxicity of manufactured nanoparticles:

The predominant process underlying the pathological effects of particles in the lungs and cardiovascular system is inflammation, involved in atherothrombosis, asthma, chronic obstructive lung disease, pulmonary fibrosis and cancer. Therefore, the ability of particles to initiate, prolong or worsen inflammation can be seen as a key property. The important finding was that NPs have a more pronounced effect on inflammation, cell damage and cell stimulation than an equal mass of particles of the same material of greater size (Donaldson et al., 2000). Surface area is the metric driving the pro-inflammatory effects particles of various sizes producing inflammatory effects that are directly related to the surface area dose (Donaldson and Tran 2002). There is significant evidence that the nanoscale materials are characteristically toxic due to accelerated generation of free radicals, hydrogen peroxide and hydroxyl atoms, driven by high surface area. While there are several proposed pathways leading to these reactive oxygen species, in the end they all ultimately result in damaged DNA, proteins, lipids and other biomolecules, inflammation and even cell death (Oberdorster et al., 2005). In cells, high surface area doses appear to initiate inflammation through a number of pathways but oxidative stress responsive gene transcription is one of the most important (Mroz et al., 2008). Preliminary data which suggest that pulmonary exposure to multiwalled carbon nanotubes (MWCNTs) and titanium dioxide (TiO_2), nano-wires may degrade the integrity of the blood brain barrier and cause brain damage primarily in the olfactory bulb, hippocampus and frontal cortex (Richard, 2009). Very little work has been done to assess

the potential reproductive toxicity of engineered nanoparticles. One brief report indicates that gold nanoparticles may have a negative impact on sperm function in vitro. A recent study found that pulmonary deposition of carbon black had negative impact on the reproductive system of male mice. Older references suggest that C60 may have fetotoxic potential. These studies are too few and incomplete to allow any conclusions regarding the reproductive toxicity of nanoparticles (Richard, 2009).

Studies of exposure to nanoparticles in the workplace:

Hazardous materials will present risks to health only if people are exposed to them. The Royal Society / Royal Academy of Engineering report, 2004, identified multiple scenarios through which humans could become exposed to engineered nanomaterials including occupational, environmental and consumer exposure. In occupational settings during the development of a new material, it is probable that this will occur under laboratory conditions. Quantities produced and numbers involved are likely to be small, but accidental releases due to spills and accidents are a possibility. Later, in commercial production, exposures may occur during synthesis or in downstream activities such as recovery, packaging, transport and storage. The quantities of materials being handled will typically be much larger. There is a notable lack of documented cases and research of human toxicity from ENM exposure. It is widely recognized that little is known about ENM safety.

Carbon-based Nanomaterials: The special case of carbon nanotubes is illustrative of many of the difficulties in assessing the toxicity of novel nanostructures. Carbon nanotubes come in two primary forms—single walled nanotubes (SWCNT) and nested multi-walled nanotubes (MWCNT). They are being produced by the ton and incorporated into many commercial products including baseball bats, bicycles and other sporting equipment. Nanotubes range in diameter from about one nanometer (SWCNT) to dozens of nanometers (MWCNT) and can have lengths into the micrometer range (Oberdorster et al., 2005). A large number of in vitro toxicity studies have been reported for carbon nanotubes, with most demonstrating unusual

cytotoxicity to a range of target cells. In some of these in vitro studies nanotubes appeared to be more toxic than quartz or asbestos, both of which induce lung inflammation, fibrosis and ultimately cancer. Several of the authors ascribed the observed toxicity to the metals contaminating impure carbon nanotube (Richard, 2009). Carbon nanotubes have high tensile strength and relatively low solubility in biological systems. They tend to cling together to make larger structures called nanoropes that are many nanometers or even micrometers in diameter. These characteristics are all remarkably similar to a naturally occurring magnesium silicate nanotube and chrysotile asbestos (Muller et al., 2005). Inhaled single and multi-walled carbon nanotubes cause rapid but transient inflammation and consistent diffuse lung fibrosis (Yu et al., 2000). Inhaled chrysotile asbestos causes macrophage death, respiratory inflammation, fibrosis, lung cancer and probably mesothelioma. However, these effects are not unique to the chemistry of chrysotile. Indeed, the amphibole forms of asbestos, which are chemically unrelated to chrysotile and do not share the lamellar structure, also induce fibrosis and cancer. The occurrence of fibrous erionite (a form of zeolite) in the Cappadokia region of Turkey and elsewhere is associated with a highly elevated risk of mesothelioma, which do not share the lamellar structure. The most notable investigations found that potential exposure during handling of carbon nanotubes in an occupational setting, nanotubes were made and harvested. Free fibers were rare almost all of the carbon nanotubes measured were in large aggregates. In this regard carbon nanotubes are very different from chrysotile asbestos (Oberdorster et al., 2005). Few studies by Maynard et al., 2004; Methner et al.,2007; Han, 2008; Bello et al., 2009, so far have attempted to assess human exposure to NPs in occupational situations. Exposure to carbon nanotubes (CNTs) has been assessed, focused on laboratory-scale activities. A number of common features may be identified. For air velocities prevailing in workplaces, airborne NPs can be considered as having no inertia. They will therefore behave like a gas, will diffuse rapidly and remain air-borne for a long time. Because of their high diffusion velocity, these particles will readily find leakage paths in systems in which the containment is not complete. Engineering control systems for NPs,

such as enclosures, local ventilation or general ventilation, therefore need to be of similar quality and specification to those normally used for gases rather than for particulate matter. Several of the studies above have considered the effectiveness of the control systems.

Titanium and amorphous silica nanoparticles: Silicon-based nanomaterials are the third most common nanomaterial type contained in consumer products which account for 17% of all nano-enabled consumer products. These include both pure silicon which is a semiconductor, and silicon dioxide or silica, an insulator. In particular, silica nanoparticles hold great promise in the biotechnology field because of their remarkable stability in biological fluids and ability to buffer with high ionic strength solutions. A review by O'Farrell et al., 2006, found that amorphous SiO_2 nanoparticles may be hazardous to humans and exhibit toxicity. A main molecular mechanism of cytotoxicity in case of amorphous SiO_2 nanoparticles appears to be oxidative damage linked to reactive oxygen species. There is a growing interest in the development of nano-composites consisting of organic polymers and titanium dioxide (TiO_2) or amorphous silica (SiO_2) nanoparticles (particles <100 nm). This is based on positively perceived characteristics of these nano-composites. Such characteristics include mechanical performance, electric behaviour, thermal properties, biodegradability, optical properties, bactericidal effects, magnetic characteristics and transport, permeation and separation properties (Ahn et al., 2009). There is substantial evidence that inhaled TiO_2 nano-particles are hazardous to humans (Oberdorster et al., 2007; Reijnders, 2009). Inhaled TiO_2 nano-particles can increase the risk of pulmonary and cardiovascular disease. There is furthermore evidence that TiO_2 nanoparticles can be translocated from the nasal area to the central nervous system via the olfactory nerve and bulb, thus posing a hazard to the central nervous system. Ingested titania nanoparticles may also be hazardous. Ingestion may lead of inflammation of the intestines and perhaps of other organs. Options for hazard reduction include better fixation of nanoparticles in nanocomposites including persistent suppression of oxidative damage to polymer by nanoparticles, changes

of nanoparticle surface, structure or composition and design changes leading to the release of relatively large particles (Oberdorster et al., 2007).

A study by Liao et al., 2009, investigated the effects of size and phase composition on human exposure to airborne titanium dioxide (TiO_2) nanoparticles (NPs) at workplaces. They reanalyzed published data of particle size distribution of airborne TiO_2 NPs during manufacturing activities and linked a physiologically based lung model to estimate size- and phase-specific TiO_2 NP burdens in target lung cells. They adopted a cell model to simulate the exposure time-dependent size/phase-specific cell uptake of TiO_2 NPs in human dermal and lung cells. Combining laboratory, field, and modeling results. They concluded that TiO_2 NP production workers have significant risk on cytotoxicity response at relatively high airborne TiO_2 NP concentrations at size range 10–30 nm.

Metal and Metal Oxide Nanomaterials: Metal and metal oxide nanoparticles can be produced by liquid-phase chemical methods, colloidal synthesis, vapor deposition techniques, and hydrolysis. Nanoscale particles of Ag, TiO2, ZnO, and CeO2 are among the most common materials currently incorporated into market goods may raise the level of public exposure in workplaces where they are being fabricated and incorporated into products. For workers handling nanomaterials, inhalation of nanoparticles is the route of occupational exposure harboring the most concern, followed by dermal exposure and ingestion. The main concern about exposure to engineered nanoparticles is that either due to their size or other novel physiochemical characteristics, they may exert unpredictable biological effects once they enter the human body. In addition to unpredictable biological effects, nanomaterials pose a higher risk for fire/explosion and catalytic reactions than their larger counterparts (Nasterlack et al., 2008).

Quantum nanodots are single digit sized particles made up of semiconductor metals that demonstrate the amazing feature of changing fluorescence wavelength based on their size. Quantum nanodots present an interesting case; many of these are intrinsically cytotoxic due to their metal content (e.g., Cd, Pb and Se). Uncoated

nanodots are quite cytotoxic, and it is possible that their toxicity exceeds the sum of the toxicity of the constituent metals (Hardman, 2006). Cho et al., 2007, showed that cytotoxicity of a variety of coated nanodots in a breast cancer cell line did not fully correlate with the generation of Cd2+ ions. Instead, the quantum nanodots were consistently more toxic that predicted by their release of Cd2+ ion. In this study quantum dot net toxicity appears to be a result of both intrinsic metal ion toxicity and induction of oxidative stress by the surface of the intact nanoparticle.

There are numerous reports of adverse lung effects and some reports of human deaths, from nanosized polymer fumes (Song et al., 2009). Two deaths were reported among seven 18- to 47-year-old female workers exposed to polyacrylate nanoparticles for 5 to 13 months. Cotton gauze masks were the only PPE used and were used only occasionally. The workplace had one door, no windows, and no exhaust ventilation for the prior 5 months. Workers presented with dyspnea on exertion pericardial and pleural effusions, and rash with intense itching. Spirometry showed that all suffered from small airway injury and restrictive ventilatory function; three had severe lung damage. Non-specific pulmonary inflammation, fibrosis, and foreign-body granulomas of the pleura were seen. Fibrous - coated nanoparticles (~ 30 nm) were observed in the chest fluid and lodged in the cytoplasm nuclei and other cytoplasmic organelles of pulmonary epithelial and mesothelial cells. Two workers died of respiratory failure. Although presented as the first report of clinical toxicity in humans associated with long term ENM exposure, many experts have expressed uncertainty that ENMs contributed to these outcomes (O'Brien and Cummins, 2008).

An approach to risk assessment of engineered nanoparticles:

In spite of the lack of toxicology data on engineered NPs, we should strive for a sound balance between further development of nanotechnology and the necessary research to identify potential hazards in order to develop a scientifically defensible database for the purpose of risk assessment. Most important, sufficient resource should be allocated by governmental agencies and industries to be able to perform a

scientifically based risk assessment and then establish justifiable procedures for risk management (Oberdorster et al., 2005).

The toxicity testing of ENMs using in vitro or in vivo assays is aimed at identifying a potential hazard by establishing dose–response relationships for characterizing such hazard. However, because a risk of adverse effects associated with ENMs is a function of hazard and exposure, the generally accepted approach is to incorporate both components into a risk assessment paradigm, consisting of Hazard Identification, Hazard Characterization, Exposure Assessment and Risk Characterization. So that appropriate risk management decisions can be made.

Hazard identification: is a critical step in exposure assessment that requires careful study of the physical and toxicological principles of a material, from thermodynamic principles, we concluded that surface reactivity may change with particle size for any material and that the unit mass and chemical reactivity of a compound increases as particle size decreases. However, the possible pathogenic mechanisms induced by particle exposure are very complex depending on the route of exposure, dose, host response and susceptibility. So, the question is, at what dose does it occur, what assay is used, in short, how realistic is the study for in vivo exposure conditions? For many nanomaterials there are insufficient physical and toxicological information (Senton et al., 2010). Toxicological research suggests that some nanoparticles may elicit a greater immune response than larger particles of the same material and total mass. Meanwhile, uncertainty remains regarding which physiochemical characteristics (e.g., size, shape, surface area, charge, surface chemistry, crystal structure, solubility, pH, reactive oxygen species (ROS) production, and state of agglomeration/aggregation), most strongly influence a nanomaterial's interaction with biological systems and ultimate hazard potential.

Tools for hazard assessment: The current quantitative support tools for investigation are specified in the Organization for Economic Cooperation and Development (OECD) guideline and the new European Union regulatory framework REACH (Registration,

Evaluation and Authorization of Chemicals) (Senton et al., 2010). They are:

(i) Standard regulatory toxicology tests: The OECD guideline for the testing of chemicals has been implemented for many toxicological endpoints. Of relevance to NPs are the acute and subchronic inhalation toxicity tests. The main limitations of these tests are: some toxic endpoints are not relevant to nanotoxicology; the difficulty in aerosolizing NPs owing to their fast rate of agglomeration and the extensive use of animals for testing.

(ii) Quantitative structure – activity relationship (QSAR): The aim of a QSAR model is to understand the properties of a chemical that influence its biological activity and to be able to predict the activity of previously untested structures/ compounds. The use of a toxicity-based QSAR is a well-established approach for predicting the toxicity of chemicals for a wide variety of endpoints.

(iii) Pharmacokinetic (PK) models: There is currently no established PK model for the distribution of NPs in the body. NPs are larger than most molecules and the standard pharmacokinetics model transport equations need to be re-examined to assess their validity for particles. An NP model is essential for describing the exposure-dose-response relationship and extrapolation of this relationship between species.

(iv) In vitro-in vivo extrapolation: Information on the toxicity of chemicals can be obtained more efficiently in vitro experiments than in vivo but translation of the results is a major issue. Dose-response modeling is required both for quantitative comparisons of in vitro with in vivo studies and to compare different in vitro studies.

Also a working group of the International Life Sciences Institute (Oberdorster et al., 2005) suggested a testing system to assess NPs at different stages, which include an emphasis on detailed physico-chemical characterization prior to and during subsequent testing in cell free, cellular and in vivo assays. Studies designed to determine whether in vitro assays are predictive for in vivo effects.

Exposure assessment: The most obvious difficulties relate to identification of small mass quantities of emission and of measuring number or surface area of emissions is a background of normal ambient particles which commonly may be hundreds of thousands of particles permilllitre. Likely expenses of monitoring such emissions in workplaces could well outweigh the benefits unless the particles prove unusually toxic, and a similar argument may apply to methods of containment and worker protection. Nevertheless, there are important scientific challenges in devising instruments that could be used both in toxicology and in environmental monitoring for measuring NPs. These challenges exist both in measuring NPs in media such as air to which people are exposed and in measuring the appropriate metric for dose when examining target organs in toxicology (O'Farrell et al., 2006).

Risk characterization and management: Risk management programs for nanoparticles should be seen as an integral part of an overall occupational safety and health program for any company or workplace producing or using nanoparticles. The key elements of an occupational management system are management leadership and employee participation; planning; implementation; and operation of an occupational health and safety system that includes systematic evaluation, corrective action, and ongoing management review. In the U.S. OSHA would set standards for occupational exposure to ENMs. Standards are relevant for ENMs under the Occupational Safety and Health Act (Balbus et al., 2007). NIOSH recommends an 8 -hour time-weighted average exposure limit of 7 μ g carbon nanotubes and nanofibers/m ^{3}air, and that employer minimize exposure to these materials (NIOSH, 2009).

Control of nanoparticles at work place:

Different approaches to assess the health risk for manufactured NPs have been proposed, such as a tool for risk level assessment and control of NPs exposure.

Elimination and Substitution: The control here is elimination of the hazard or substitution with a less hazardous or nonhazardous substance but, unfortunately, this approach may be difficult regarding nano-materials,

which are generally produced precisely because they exhibit unique commercially exploitable properties.

Engineering controls: ENM exposure can be reduced through the use of engineering controls, such as process changes, material containment, and enclosures operating at negative pressure compared to the worker' s breathing zone; worker isolation; separated rooms; the use of robots; and local exhaust ventilation (LEV).

Process/source enclosure (i.e., isolating the ENM from the worker) can be aided by, chemical fume hoods, biological safety cabinets (BSC), or an externally -vented LEV system. However, one should also consider that these methods can release ENMs into the environment, potentially creating environmental pollution and loss of costly material (Yokel and MacPhail 2011).

Local exhaust ventilation: Local exhaust ventilation systems appear to be effective for capturing airborne nanoparticles. This is based on what is known of nanoparticle motion and behavior in air. Current scientific knowledge about the generation, transport, and capture of aerosols indicates that established criteria for maintenance and use of ventilation systems recommended. It should be applicable to control airborne exposure to nanometer-scale particles at least to the same levels as fine particles. Nanoparticles have low inertia and will generally follow the surrounding airflow. The high-diffusion behavior of nanoparticles increases their opportunity to come in contact with filter elements (e.g., fibers) and be collected. Therefore, it is reasonable to anticipate that a well-designed exhaust ventilation system with a high efficiency particulate air (HEPA) filter should remove nanoparticles as effectively as for fine particles (Schulte et al., 2008).

Administrative Controls: Administrative controls are policies aimed at limiting worker exposure to a hazard, typically by altering the amount of time a worker is potentially exposed and by the implementation of good work practices. In nanotechnology laboratories, administrative controls also may include strict practices for maintaining clean room conditions. Critical in the use of administrative controls is weighing the effects of minimizing individual workers'

exposures against increasing the total number of workers exposed.

Personal Protective Equipment: Use of personal protective equipment (PPE) such as respirators, gloves, and protective clothing is the least preferred method for preventing worker exposure to a hazard because it places the responsibility for preventing injury or illness on the worker.

In the UK, the Health and Safety Executive (HSE), 2005 has recently published guidance on safe handling of carbon nanotubes (CNTs). The HSE views CNTs as being substances of very high concern and have stated that a precautionary approach should be taken to the risk management of all CNTs, unless sound documented evidence is available on the hazards from breathing in CNTs. If their use cannot be avoided, the HSE expects a high level of control to be used including a recommendation to control exposure at source by carrying out all tasks, including packaging for disposal, in a ducted fume cupboard with a high efficiency particulate air (HEPA) filter, or by using other suitable effective local exhaust ventilation with a HEPA filter.

The British Standards Institute, 2009, provides step-by-step guidance to the general approach to management of risks, information needs, hazard assessment, measurement of exposure, methods of control and disposal. It is intended to help manufacturers and users work with nanomaterials in a safe and responsible way.

Occupational medicine and engineered nanomaterials:

Broadly constructed, occupational medicine programs attempt to limit the health effects of chemical, biological and physical stressors in the work place. The goals of an occupational medicine program are:

1- Prevent occupational diseases from occurring.

2. Quickly detect occupational diseases that do occur.

3- Intervene to cure occupational diseases.

1-Prevent occupational diseases from occurring

1-Workplace exposure monitoring: Exposure to chemical agents is assessed either by environmental monitoring (e. g. air monitoring

and dermal exposure assessment) or biological monitoring (e.g. blood and urine analysis). The results of these assays are compared to established limits as an index of the risk.

Exposure monitoring: For most nanoscale particulate matter, there are no accepted exposure monitoring methods, no exposure standards, the effectiveness of traditional control methods is only now being elucidated, the target organs are not always obvious and the impact of pre-existing conditions on risk is not clear. This makes it very difficult to establish an evidence-based program to prevent the manifestation of occupational disease related to nanoparticles. NIOSH has proposed a draft exposure limit of 0.1 mg/m^3 for nanoscale TiO_2 , which stands alone as a widely recognized exposure standard specific for engineered nanostructured materials in the U.S.(Evans et al., 2008).

Handheld condensation nuclei counters that can enumerate airborne nanoparticles down to 10 nm in diameter are used, but it is difficult even to obtain relative measurements with these instruments due to the extremely high and variable background level of natural and anthropogenic ultrafine particles (Heitbrink et al., 2007).

Size-selective real time aerosol monitors for measuring nanoscale particulate matter, such as mobility particle spectrometers, are available but this equipment is very expensive, large and requires special training to operate.

Particles can be collected on filters or other media with subsequent analysis by electron microscopy. This allows for specification and sizing of nanoparticles, but at huge cost in terms of time and expense and requires expertise that is of very limited availability right now. As the particle surface area is likely the most relevant exposure metric for many nanoscale particles, unfortunately, there is no generally accepted sampling method to evaluate particle surface area.

2-Establish workplace controls: Controls are established to reduce employee exposure to occupational stressors. Controls may include engineered controls (e.g., ventilation, filtration and enclosure), administrative controls (e.g., safe work practices and training) and personal protective equipment (e.g., gloves, respirators and goggles). Overwhelming data from numerous

investigators (Kim et al., 2006; Fissan et al., 2007; Huang et al., 2007) showed that management of exposure to nanoparticles can in most cases be achieved using familiar engineered, administrative and personal protective control measures.

3-Medical pre-screening for people at elevated risk: Prior to exposure to an occupational stressor, the working population is screened for conditions that may put them at elevated risk of occupational disease. At risk employees may be offered alternative assignments or enhanced protection to reduce their chances of becoming ill.

4-Medical surveillance: Occupational health surveillance is the systematic collection of exposure and health data for a group of workers with the goal of early detection of disease and ultimate prevention of disease. It can also be used to determine whether the hierarchy of controls for prevention of illness and injury are effective. Basically, the decision to carry out a targeted occupational medical surveillance requires (1) knowledge about the existence or at least possibility of an exposure to a health hazard, (2)knowledge about specific health effects caused by such an exposure, (3) the availability of tests with a known sensitivity and specificity to detect such health effects in an early preferably reversible or treatable stage and (4) establishment to a sufficient degree of the causal relation between exposure and effect (O'Farrell et al., 2006).

2-Detection of occupational disease:

The second goal of occupational health surveillance is to detect subclinical signs of illness in a worker population, with an eye toward quick intervention to prevent development of overt disease. This process is most commonly called medical monitoring in the United States and is mandated by the Occupational Safety and Health Administration for some chemical agents such as asbestos, lead and benzene (Ahn et al., 2009).

For most nanomaterials, it is unclear what diagnostic studies should be included in a medical monitoring program. While many suggestions have been, including measurement of heart rate variability, pro-inflammatory

cytokines, lung CT studies, liver enzyme tests, etc., none of these rise to the level of validation normally required for inclusion in a targeted medical monitoring program. The sensitivity, specificity and risk/benefit ratio of such testing is unknown with respect to most nanoparticles (Fritz et al., 2010).

NIOSH, 2007 has recently published a draft guideline that proposes, insufficient scientific and medical evidence now exists to recommend the specific medical screening of workers potentially exposed to engineered nanoparticles.

3- Treatment of the disease:

The third goal of occupational medicine it to treat those injured by their experience at work. This might be affected by removing the injured individual from further expo-sure via transfer, or via some form of treatment. Medical removal is not always effective at limiting the progression of disease and raises real concerns for both the employer and employee (Richard, 2009).

Conclusion

The emerging nanotechnology revolution is another grand step in the industrial revolution. Current nanotoxicological researches aim to identify the physico-chemical characteristics of NPs responsible for the observed health effects. These results could be incorporated in the design of new engineered NPs. The challenge is to produce new nanomaterials that are without adverse characteristics and still fulfill the industrial requirements. This approach would have the advantage of initiating a sustainable and safe nanotechnology. Occupational health professionals such as physicians and industrial hygienists have to take steps to develop hazard assessment, exposure control and health monitoring strategies. The goal should be to anticipate and mitigate adverse consequences before people are injured or the environment is contaminated.

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