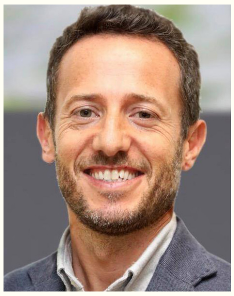
WORK AND NANOTECHNOLOGY

Francisco Silva
Head of OSH Laboratory at the Technological Centre for Ceramics and Glass, Portugal

Paul Swuste
Associate Professor, Delft University of Technology, the Netherlands

Pedro Arezes
Full Professor at the School of Engineering of the University of Minho, Portugal



This paper will address two topics. It will start with a question 'where do we stand now', and ends with a reflection 'what can we expect for the near future'.

I. Where do we stand now?

It is estimated that a few tenths of million workers are already, or will be exposed in years to come to nanomaterials in theirs workplaces, mainly in research and in industry. The nanotechnology field has been increasing for the last decade, with huge amounts of money invested. This growth of activity has been followed by development in the field of nanotechnology safety, or as it is commonly named, the nanosafety field.

Despite the recent development of nanotechnology, it is being widely estimated that its impact will be somehow similar to what happened with the discovery and use of electricity at the end of the 19th century. This huge impact is related to the nature of this technology, as nanotechnology is a sort of link between the physical, digital and biological systems. The used of nanoscale allows these systems to communicate mutually, for example, establishing connections between cells, metal, ceramics, etc. Nanotechnology will allow, for instance, the development of nanodevices that will be able to act inside our body and search for, and eliminate undesired elements, such as virus, bacteria or cancer cells, but also to print 3D body tissues and organs, to develop ultra-resistant materials with augmented properties, to develop body-embedded sensors able to identify any body change, or create new materials able to store, transport and provide energy. The possibilities are huge and right now we still can't figure out most of the possibilities of this technology. Being so disruptive, it is expected that this technology will lead to a change of the way we produce, consume, communicate and live. Nanotechnology will certainly have a major impact. Some authors are discussing how these developments will burden our current society.

However, much of the advances of this technology can be overshadowed by the potential human health effects resulting from emission, and consequently exposure to nanomaterials.

Even if the uncertainty is still a major issue in the current domain of nanotoxicology, it is also widely accepted that physical and chemical properties of nanomaterials, such as its size, shape, surface areas, and agglomeration are very different from the properties of the same materials at a macro scale. Those characteristics of nanomaterials can lead to a different interaction with human cells, resulting in inflammatory processes and, ultimately, in cell death. Most of the authors believe that those effects are mediated by oxidative stress. Other materials properties are also important, such as the solubility, which has an important influence in the persistence and durability of nanomaterials in living organisms and environment. Being so widely developed and applied, nanomaterials will be an important elements of the future workplaces, both at an industry level and also at an user level.

Accordingly, it seems clear that one of the main future challenges for researchers, and occupational safety and health practitioners will be the reduction of the before mentioned uncertainty within the nanotoxicology domain. Some major advances have been achieved. New and emerging approaches including high-throughput screening and omics-based systems toxicology tools are been adopted in nanotoxicology. Unfortunately results of nanotoxicology research are not yet fully reflected in health and safety practices in workplaces. The communication channels between nanotoxicologists and safety practitioners (to exposed workers in rigor) still need improvement.

Nowadays, there is a wide consensus in the scientific and business communities concernin risk management and exposure assessment strategies. Concerning exposure assessment, the Tiered Approach was first proposed by a group of German institutions aiming to harmonize the occupational hygiene approach to nano-objects exposure in workplaces. More recently, and also considering other proposed strategies to assess nano-objects exposure, the Environmental Directorate from Organisation for Economic Co-operation and Development (OECD) adopted a similar approach. The model proposed is based on the increasing complexity from tier 1 to tier 3. In tier 1 – Information Gathering, the use of Control Banding risk assessment tools is considered, whilst in tier 2 – Basic Exposure Assessment, portable equipment, such as Condensation Particle Counter (CPC) is used to assess the workers' exposure and tier 3 – Expert Exposure Assessment, complies the use of state-of-art measurement equipment, including collection of nano-objects in filters followed by electronic microscopy and/or chemical analysis.

Risk management in nanotechnologies could be supported by control banding tools, developed during the last decade for specific use with nanomaterials. Control Banding is a general term referring to a qualitative risk assessment that stratifies nanomaterials hazards at a given workplace across two sets of levels or bands, the hazards bands and exposure potentials. Although these qualitative methods have limitations concerning risk assessment, they give helpful support to risk management. For risk control a recommended order of priority is: 1/substitution or elimination; 2/isolation; 3/engineering controls; 4/administrative controls; and 5/personal protective equipment (PPE). Several national and international bodies wrote recommendations regarding occupational risk management in nanomaterials laboratories and industrial settings. Although these recommendations are relevant, there are many uncertainties concerning the effectiveness of recommended measures controlling the risks, in particular, considering the wide range of existing nanomaterials.

II. What can we expect for the near future?

Special focus should be pointed to safety assessment during research and development (R & D) phases. Several authors have called for attention to safe-by-design approaches introducing risk management in the products and processes design phase. "Safety- by-design" to reduce emission, "Safe innovation", and "Responsible development" should be concepts, if not mandatory, for nanotechnologies market self-regulation. Corporate social responsibility is essential as a driving force for risk prevention, as well as regulation, including both soft and hard law. Researchers and manufacturers need to integrate safety in R & D processes, and demonstrate the harmless character of the materials, products, and production process.

In a frequently cited article, published in 2006, a model for the evolution of nanotechnology is presented, including different generations of nanomaterials with an increasing complexity. At present, we are dealing with a first generation of passive nanostructures and to some extent with second generation nanotechnologies which include active nanostructures. Some authors divide the nanotechnologies progression in 3 ways: incremental, evolutionary and radical. Incremental nanotechnology corresponds to improvements of present day use of nanomaterials; evolutionary nanotechnology corresponds to a higher level of complexity in systems, including areas such as drug delivery systems, medical imaging, and energy conversion; and radical nanotechnology deals with even more complex systems or systems of systems, including nano robots, self-replication, or molecular manufacturing. But complexity leads to more uncertainties. Despite a current appropriate OSH approach on nanomaterials, there will be always new conditions imposing new challenges. Existing risk assessment management strategies, based on the existing knowledge, are able to deal with the most common nanomaterials like titanium dioxide, fumed silica or carbon nanotubes. These strategies are inadequate when workers are exposed to more complex nanomaterials. The main challenge in nanotechnologies is to harmonize the great technological advances with risk mitigation.

It is important to identify and validate the most appropriate risk management approaches for nanotechnologies. At the same time, occupational exposure limits must be established, at least for the more common nanomaterials in use nowadays, including carbon nanotubes, titanium dioxide, amorphous silica and silver, along with definition of the standard sampling and analysis methods. It is highly speculative but artificial intelligence could bring unpredictable developments to exposure and risk assessment methods. The improvements could appear in nanotoxicology, exposure assessment equipment, and also in risk management tools.

Regulators should work with researchers in order to deliver legislation and regulations for nanotechnologies that could reflect the most reliable approaches to workplace safety.

One general framework widely open to integrate new knowledge is advantageous, comparing with "hard" and strict rules that need more time for approval and get outdated fast. Risk assessment and management approaches will have to deal increasingly with uncertainty. Integrative and multidisciplinary approaches to risk assessment and management is necessary and this is obvious when looking at the development boom of materials with increasing complexity.