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André Gazsó*, René Fries, Robert Piringer

Nanomaterials and occupational safety – An overview

Summary

Nanomaterials and products containing such materials are already in widespread use because they exhibit technologically interesting, nano-specific features such as increased tensile strength, improved electrical conductivity, special optical characteristics or special medico-chemical properties. Nonetheless, the same features that make these substances so interesting technologically potentially harbor risks for those persons who handle them. This is because small particle size, coupled with increased reactivity due to special surface features, determines their biological activity and therefore toxicity. The increasing applications are exposing ever more employees – especially those working in research laboratories or in industrial production and processing – to nanosubstances. This makes occupational safety a major issue from a regulatory standpoint. Based on the available literature on occupational safety, the following nanomaterial-relevant topics have been identified: health risks, adaptation of detection and measurement methods, actual exposure scenarios at the workplace, definition and compilation of existing worksites for nanomaterials, recommendations for worker safety by the authorities and by industry, as well as preventive occupational medical care.

* *Corresponding author*

Introduction

Assessing the potential risks of nanoparticles represents a special challenge for those institutions responsible for employee safety and health. The European Action Plan on Nanotechnology, along with all other national action plans, has sections that call for guaranteeing safer workplaces in the nanomaterials sector (see below).

In recent years, many authorities and research facilities have provided updated, useful overviews on the health repercussions of particulate matter[1] and synthetically produced nanoparticles[2]. Several studies report data on exposure levels of nano-substances at the workplace.[3]

Although many details on the action mechanisms and resulting risks remain to be clarified, there is a clear recognition of what needs to be done to meet the occupational safety demands of the European Commission for a responsible handling of nanomaterials:

- In light of the potential risks, the available studies uniformly recommend preventive measures. Contact with nanomaterials should be minimized to the extent possible or a switch be made to less problematic processes. The demonstrated effectiveness of technical laboratory safety equipment and protective clothing shows that this is possible in the nanoparticle sector as well;
- Secondly, a comprehensive safety concept should form the framework for dealing with these new chemical substances. All the key publications on this topic therefore underline the importance of clear rules – geared toward employee safety – in laboratories and production sites.
- Moreover, there is wide-ranging acknowledgement of the considerable gaps in knowledge in certain areas, above all in detecting and identifying nanosubstances, but also regarding potential health risks. This has hindered establishing binding agreements on limit values for acceptable exposure to nanosubstances.

This report, after presenting the policy framework conditions, provides an overview of the key issues: ultrafine particulates, detection and measuring methods, and nano workplaces. This is followed by a discussion on recommendations regarding occupational safety in the nanosector and on safety data sheets as one instrument in this effort.

Policy framework conditions – nano action plans and occupational safety

The Austrian Nano Action Plan (NAP) contains specific recommendations on occupational safety; the responsible authorities include the Austrian Social Insurance for Occupational Risks (Allgemeine Unfallversicherungsanstalt: AUVA), the Central Labor Inspectorate (ZAI) of the Federal Ministry of Labor, Social Affairs and Consumer Protection (BMASK), the Federal Environmental Agency (Umweltbundesamt) and, in general, the social partners.

- Information events by the AUVA and the social partners should provide targeted information and help promote awareness in businesses.[4, 5]
- Education and training programs should be developed to improve the expertise of labor and chemical inspectors, occupational health specialists, health and safety officers, and of works council representatives.[6] The goal is to provide a level of qualification that helps implement and supervise the safe handling of nanotechnologies and nanomaterials.

- The NAP also calls for an overview of nanomaterial applications and the types of workplaces where such materials are handled. The AUVA and BMASK/ZAI are to be responsible for compiling and regularly updating the respective list. The list is designed to simplify the focused counseling of businesses and surveillance by the authorities.[7]
- Finally, over the medium term, the foundations for measuring nanoparticles, especially in the air, at potentially exposed workplaces are to be developed. Potential measures include
  - Exposure scenarios for the workplace,
  - Health-relevant limit values for nanomaterials, even if these are only preliminary, and
  - Record-keeping requirements on the exposure to nanomaterials in especially threatened workplaces.[8]

  All of these measures are designed to make the occupational exposure of workers a more transparent issue and to provide a basis for evaluation in the event of work-related illnesses.
- Finally, a guideline should document the current state of knowledge on the actual threats at the workplace and help improve occupational risk management.[9] The AUVA published its own instruction sheet (M310) on this issue in 2011 (see below).

The Austrian activities related to occupational safety and worker protection are therefore clearly in line with the European Action Plan's efforts for a safe and responsible development of nanotechnologies. Thus, the precautionary principle can be applied to initiate specific measures to protect the population (consumer protection, occupational safety, product safety) even if the state of scientific knowledge is unclear or conclusive research results not yet available. At the same time, a public discussion about safety issues should create awareness in all stakeholders and thus promote balanced management decision.

Like many comparable documents, the recently published German "Action Plan Nanotechnology 2015" reaches similar recommendations (development of procedures to determine exposure, strict occupational safety measures, independent safety research at the earliest possible date).[10]

It is unclear how nanotechnology research and applications will develop over the next few years and what a safe strategy in handling these technologies will look like. Nonetheless, the member states have developed a common position on how to interpret the European Action Plan: consumer and worker safety take on an increasingly central role. This clearly reflects an attempt to promote independent safety research and apply the precautionary principle to avoid repeating earlier mistakes in technology policy. This is accompanied by attempts to remove potential barriers to implementation by broadly involving the public at an early stage. The degree of success will depend on how effective the risk management measures are and how authentically the participating parties act.

Overview – key topics in occupational safety

Employees in research laboratories are the first to handle new materials. With the increasing application of nanocomponents, workers involved in industrial production and manufacturing processes come into contact with these materials. The German Council of Environmental Advisors also emphasizes, in connection with "Precautionary strategies for nanomaterials", that one should concentrate "above all on a potential exposure at production and processing worksites".[11] That is where these substances create special challenges:

- Many of their characteristics – high reactivity and small particle size – make these materials technologically interesting, but also raise concerns because they could be associated with new health risks for employees.
- The lack of robust monitoring systems for identifying nano-aerosols makes it very difficult to determine contamination levels in the ambient and what measures can reduce such contamination.

Ultrafine particulates and health risks

Ultrafine particulates typically originate from combustion processes. They are differently sized, as opposed to the homogeneous, synthetically produced nanoparticles.[12] With regard to potential health risks, however, the experts of the Swiss Federal Office for the Environment (Bundesamt für Umwelt) see parallels. Their report "Synthetic Nanomaterials", presented in 2007, establishes a link between manufactured particles and atmospheric particulates.[13] Review articles on nanotoxicology point to the increasing amount of particles of this size in the biosphere, underlining potential new toxic effects.[14] [15] The most important sources for contamination with fine and ultrafine particulates are human activities.

To date, only the particulate fraction 'PM-10' and 'PM-2.5' (referring to aerosol particles with diameters Ø < 10 µm beziehungsweise Ø < 2.5 µm) has been measured continuously. Only these coarser particles are regulated by limit values.[16, 17] No regulations currently exist for dust particles in the atmosphere with sizes below 100 nm, which are referred to as fine particles (or ultrafine particles (UFP)).

In recent decades, toxicologists have gained important insights by studying the effects of ultrafine particles in the atmosphere.[18] More exact analyses[19] reveal that specifically the smallest aerosol particles – i.e. the UFP fraction with sizes below 100 nm – cause health problems. A detailed presentation on the potential health impacts of nanoparticles can be found in the NanoTrust-Dossiers 012en, 014en and 021en.

Detection and analytical methods for nano-aerosols

The specific features of nanoparticles, especially their small size, prevent direct observation with optical instruments and pose special analytical challenges. Sophisticated particle measurement instruments have already been developed for use in atmospheric and aerosol physics; these are now being applied to synthetically produced nanoparticles as well. Measurements continue to be difficult because technical nanoparticles must be distinguished from the many normal dust particles. One particular challenge is to detect fiber-shaped dust and other particles, especially long and thin fibers ('high aspect ratio nano-objects' – HARN). A more precise overview about quantifying and characterizing nanoparticles in the atmosphere can be found in NanoTrust-Dossier 025en.

Estimating the types and numbers of nano workplaces

The present statistics on the number of employees who deal with synthetic nanosubstances at their workplaces are not very reliable because clear definitions for nanosubstances are missing. For example, it remains unclear whether those workplaces exposed to unintentionally produced particulates are to be included. Today, no separate identifiers are being used in the nanotechnology sector, even in industry statistics. All the data are therefore based on random samples and estimates, such as those produced in a BAuA questionnaire campaign.[20]

Currently, the proportion of employees in the nano-sector is often listed as being less than 0.1 percent of the total production sector (e.g. in Switzerland). There is broad agreement that the number of persons involved with synthetic nanoparticles will rise rapidly in the near future: the EU authority for occupational safety estimates that there will be ten million workplaces in nanotechnology by 2014. Within the EU, this would mean nearly six million employees in the nanotechnology sector.[21]

Recommendations on the national level

In summer 2011, the Austrian Workers' Compensation Board (AUVA) published an official sheet "Nanotechnologies – Occupational and Health Safety" (M 310)[22] designed to inform employees about protective measures for work-related exposure. The AUVA assumes that "the hierarchy of protective measures … is also [valid] for nanoparticles." Protective measures are to be established – as in other cases – based on a multi-level concept (substitution, technical, organizational and personal protective measures, see below).

A "Guidelines for risk management in handling nanomaterials at the workplace" was commissioned by the Central Labor Inspectorate in November 2010. It was designed to provide practically oriented and easily understandable support, especially for smaller and medium-sized businesses.[23] This guideline orients itself according to traditional risk assessment methods for chemical agents. Beyond a list of recommended operational steps, it also contains a collection of summary-like descriptions (so-called theme sheets) on a total of 15 topics including definition and characterization, risk assessment, risk management, and measurement of nanomaterials. This serves as an initial orientation.

Recommendations on the international level

Internationally, a series of concise suggestions ('best practices') have been presented to deal with the risks at the workplace in the nanotechnology industry. Examples include the recommendations from Australia[24] as well as from the German Federal Agency for Industrial Health and Safety (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin: BAuA)[25] and the Swiss National Accident Insurance Fund (Unfallversicherungsanstalt: SUVA).[26] Similar recommendations have been made by the French[27] and US occupational health and safety agencies[28] as well as by the State Institute for the Environment (Landesanstalt für Umwelt, Baden-Württemberg, Germany).[29] Moreover, several thorough overview articles have recently been published on measures designed to improve occupational safety and preventive health care.[30]

In key sectors, the documents arrive at matching recommendations in the fields of both prevention and risk management:

- *Precautionary principle:* protective measures are to focus, as a precaution, on the suspected harmful features.
- *Hazard identification:* Safety efforts initially require recognizing potential threats (although this is not always possible).
- *Minimize the impacts* by applying a range of measures (reduce the number of exposed workers, lower concentrations).
- *Substitution:* replace substances posing a health risk with less harmful ones; bind dust-like nanomaterials.
- *Technical protection measures:* the goal is to identify, limit or capture hazardous vapors and particulates.
- *Organizational protective measures:* for example by restricting access.
- *Personal protective measures:* respiratory protection (with adequate particle filters), protective gloves, closed safety goggles, protective clothing as well as instruction in decontamination procedures.
- *Hygiene measures:* suitable opportunities to wash clothes and to safely store street clothes.

Handling nanomaterials in laboratories

In 2011, the US Research Council provided the first specific recommendations for handling nanomaterials. Moreover, numerous university labs have published handling instructions and regulations especially designed for nanomaterials.

The 'Board on Chemical Sciences and Technology' of the US-National Research Council has been publishing a handbook on safety aspects of chemistry laboratories since the 1980s. The most recent edition of this handbook presents recommendations on handling nanomaterials and on managing environmental and safety risks.[31] The key recommendations are:

- orientation based on trustworthy sources[32]
- precise system description in order to estimate the risks beforehand
- multi-level approach toward the control of nanomaterials ('graded approach').
- establish technical control measures ('engineering controls')
- monitoring: determine particle concentrations and compare with background values.
- regular cleaning ('housekeeping')
- adherence to general work rules ('work practices')
- instruction of laboratory personnel and especially of cleaning staffs
- reporting of incidents and health complaints.

Recommendations by industry

The documents produced by (or in cooperation with) industry typically provide the basic guidelines for comprehensive risk minimization. They include recommendations by the German Chemical Industry Association (Verband der Chemischen Industrie),[33] a guideline by the Netherlands Federation of Chemical Industries (Dachverband der Chemiebetriebe)[34] as well as a compilation by the German Federal State of Hessen, which suggests guidelines for the "safe use of nanomaterials in the lacquers and paints sector".[35] This is accompanied by an Australian study on safety procedures in the nanotechnology industry.[36]

The current guidelines from the Netherlands (May 2011) are designed to support employers and employees in deciding on suitable measures for optimal safety and health at the workplace. A 6-tiered process is suggested: inventorization of the substances, classification, exact documentation of the working steps, classification of exposure, possible control processes, and implementation of control measures. Those affected should be involved in the decision-making process.

Effectiveness of protective measures

Technical and organizational measures that laboratory personnel can use to protect themselves against the effects of hazardous gases, chemicals, biological or radioactive substances have been tested for years and proven successful. The effectiveness of such measures – especially of laboratory fumes, filter systems and personal protective clothing – has also been tested and demonstrated for nano-aerosols.

A compilation published by industrial scientists from the US and Finland in 2008 determined that synthetic nanoparticles follow the well-known principles of aerosol physics and flow dynamics and that the appropriate filters are therefore also highly effective in removing nanoparticles.[37] In the framework of a funded EU project, detailed studies were conducted on the effectiveness of such protective equipment.[38]

Moreover, a publication by the OECD working group on handling of chemicals, published two years ago, contains recommendations for the selection of personal protective equipment at nano workplaces. Nonetheless, testing procedures that consider the specifics of nanoparticles are lacking. This calls for caution in evaluating the degree of protection afforded.[39]

Since 2006 the Federal Agency for Industrial Health and Safety (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin) in Germany, in cooperation with the Chemical Industry Association (VCI), have conducted surveys in industrial businesses in order to obtain more information about nanomaterial exposure at the workplace and the protective measures taken there. The vast majority of the cooperating companies (93 %) stated that they introduced safety measures in ventilation, in process design and in providing personal respiratory equipment. Nonetheless, the companies were unable to quantify the exposure to nanoparticles and particulates in almost 80 % of the workplaces.[31]

Safety data sheets

Safety data sheets (SDS) are the most important source of information on the material properties for production and further processing. They contain data on potential threats in handling chemicals and on the necessary protective measures at the workplace. A SDS is designed to follow the chemical substance across its entire supply chain. This standard has not convincingly been met: reviews at the European level show that the information in the safety data sheets is mostly incorrect even for conventional preparations.[40] According to a Belgian study[41], the deficits of many SDS often prevent successful use in protecting company workers.

The deficiencies in the information on synthetic nanomaterials have been examined more closely: an expertise from Australia[42] determined that the SDS data for these substances were mostly unreliable. In particular, they contain virtually no information on nano-specific risks. Moreover, suggestions on handling are typically made based on the known bulk materials (which are classified as harmless). This was determined in an international study in 2008.[43]

Repeated demands have been made for correct descriptions of the special features of nanomaterials. The German Council of Environmental Advisors (SRU) has elevated improved disclosure requirements through SDS to one of its key demands.[12] Suggestions and guidelines have been presented by Germany[44] and Switzerland[45]. As of 2015, an amendment of the European REACH regulations will prescribe several mandatory measures for SDS.

Conclusions

Worker protection and lab safety are priority topics because the most exposed persons – those who are the first to come into contact with nanomaterials – are those involved in the production, transport and processing of these materials. Although improvements are constantly being made to occupational safety (identification of workplaces, guidelines for recommendations in handling nanomaterials, exposure scenarios, modification of analytical techniques, etc.), occupational safety continues to pose major challenges to the responsible authorities. As far as identifying and characterizing actual gaps in our knowledge is concerned, the following specific areas deserve mention: (1) the classification of particularly hazardous nanomaterials, (2) resolving the question of whether synthetic nanoparticles can be interpreted as beings "new substances", (3) which characteristic features and which analytical techniques should be used to determine exposure levels to nanoparticles, (4) which exposure levels to nanoparticles are present at the workplace, (5) what measures are adequate to protect workers and (6) how can these measures be implemented and controlled.

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