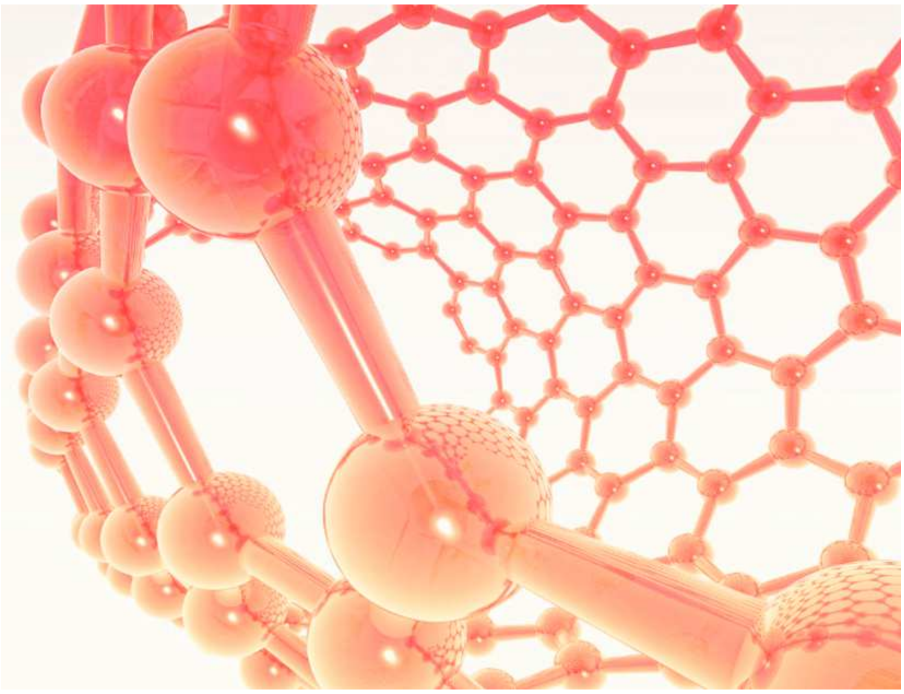
# Guidance on Exposure Characterization for Airborne Nanoparticles



*LIFE REACHnano*

*Development of a web based REACH Toolkit to support the chemical safety assessment of nanomaterials*

Technical Guidances series - 2015

*LIFE11 ENV/000549*

www.lifereachnano.com

# Guidance on Exposure Characterization for Airborne Nanoparticles

This publication was published in 2015 with support from the European Union's LIFE Fund in the framework of LIFE programme environmental policy and governance entitled "LIFE REACHnano - Development of a web based REACH Toolkit to support the chemical safety assessment of nanomaterials" (LIFE11 ENV/ES/000549)



Printed in Spain



First Edition, 2015

This technical guidance has been produced by the REACHnano Consortium:

# Contents

# 1. Introduction and vision

The use of engineered nanoparticles (ENPs) has promoted the development of a new generation of smart and innovative products in a large number of industrial sectors, many of them enlisted in Fig. 1 (1). However, along with the benefits, there is an on-going debate about their potential effects on the human health and the environment: materials with one or more dimensions at nano-sized scale have different properties from their larger physical forms, thus they may interact differently with environmental and biological systems (2).

Since these effects are not fully studied and understood yet, a great part of this **nanotechnology progress is growing and developing without any special rules or regulations.** Such an uncertain atmosphere has caused increased concerns about the effects of nanoparticles, therefore, adequate studies to determine the real risks of the use of nanoparticles are required.

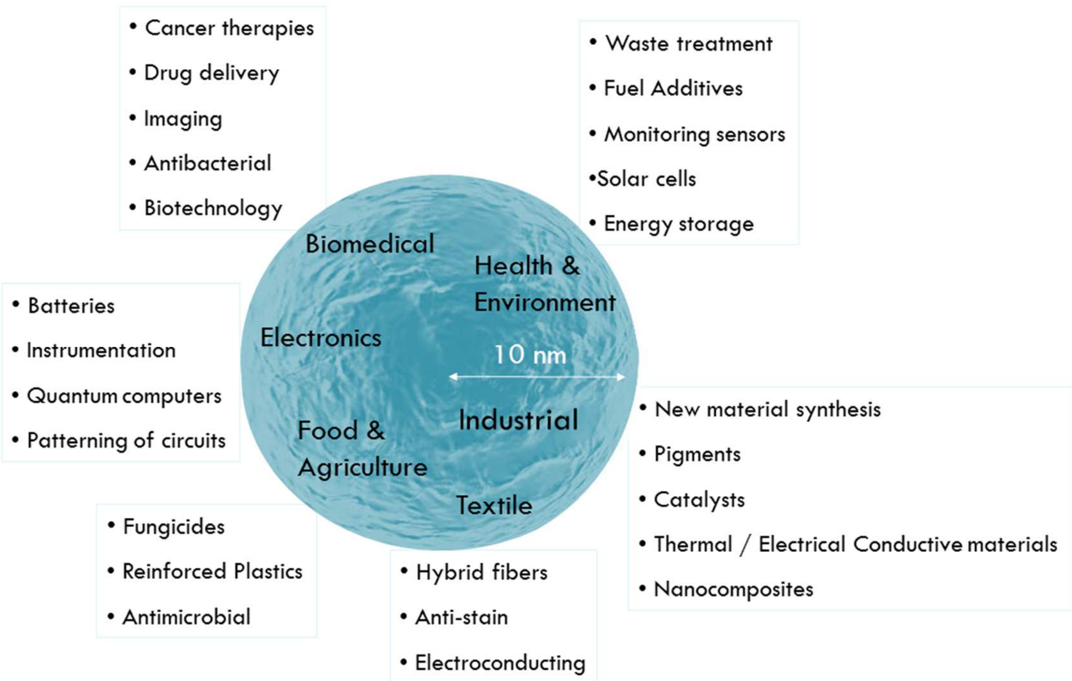



Figure 1: Scheme of some of the numerous uses and applications of nanoparticles.

In this regard, the European Union created on 1st June 2007 the Regulation (EC) 1907/2006, concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals, mainly known as REACH.

The scope of REACH refers to substances in whatever size or forms, thus also apply to nanomaterials. However, a degree of uncertainty exists concerning the adequacy of REACH regarding nanomaterials and consequently this is one of the key challenges in relation to adapting REACH to address the properties of nanomaterials.

## 2. Scope of this Guidance

Along with the rapidly increase of the use of nanomaterials such as carbon-based nanoparticles (fullerenes, nanotubes), metals or metal oxides (Ag, ZnO, $SiO_2$, $TiO_2$,…) or natural inorganic compounds, including asbestos and quartz, the concern is whether the benefits of using nanoparticles can overcome the economic costs, environmental impacts and unknown health risks for workers and consumers resulting from their use.

**The presence of a hazardous substance does not lead to a risk if there is no exposure.** The risk characterization of such nanoparticles, on the other hand, has to consider several characteristics from the material, such as its mobility, reactivity, environmental toxicity, and stability, but also from the process and the operative conditions: time of exposure, used amounts, temperature, etc. (Figure 2).

Hence, in the coming years, a remarkable challenge for the nanotechnology industry, the academia and the regulators will be the generation of new data on the levels of exposure in workplaces. Recent studies show how the most extensive exposures to ENPs likely occur in the workplace, particularly research laboratories, start-up companies, pilot production facilities, and operations where ENPs are processed, used, disposed, or recycled (3).

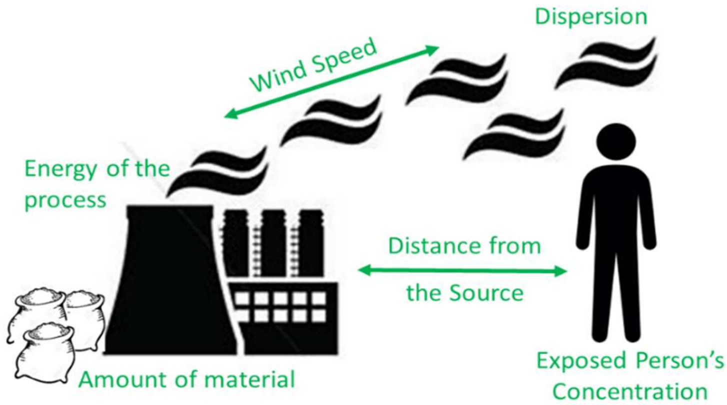



Figure 2: Several variables determine the risks of the exposure to a given nanomaterial.

**The main goal of this guidance is to provide the tools necessary to carry out a prior estimation of the exposure levels at the workplace** by describing the strategies to identify the possible areas and situations in which the worker can be exposed to ENMs, the approach to quantify these levels and how to interpret the results. In base of these results, there will be a list of mitigation measures to implement in order to increase the safety at the workplace.

In the occupational context, it has been demonstrated that workers have the potential to be exposed to uniquely ENPs with novel sizes, shapes, and chemical properties, at levels far exceeding ambient concentrations (4).Among the routes of exposure, **inhalation is the most common pathway for airborne ENPs in the workplace, and the most critical** (5; 6; 7; 8). The skin has also been investigated, however, most studies have shown little to no transdermal ENPs absorption (9), and gastrointestinal exposure can occur from intentional ingestion, unintentional hand-to-mouth transfer or from inhaled particles greater then 5 µm that are cleared via the mucociliary escalator, among others (4).

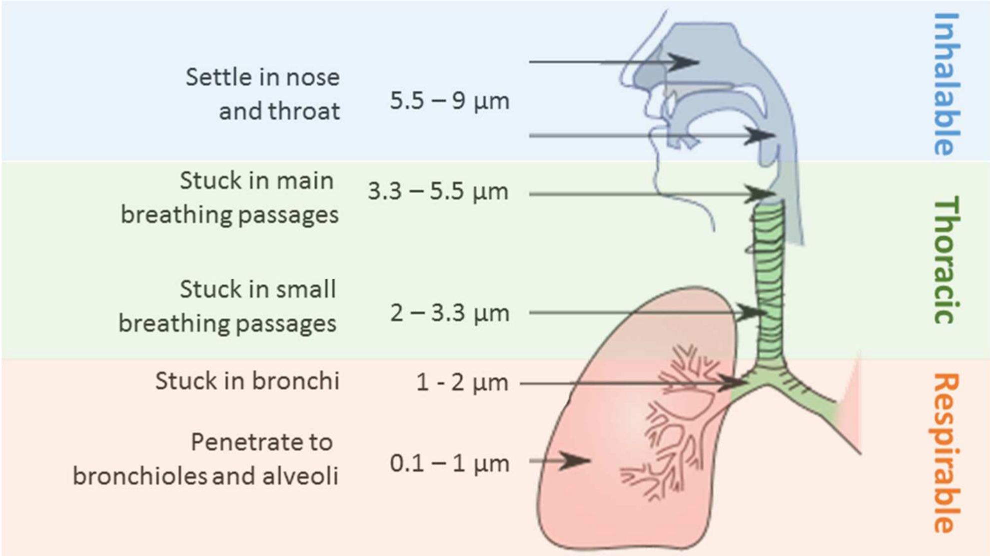



Figure 3: Particle deposition in the respiratory system.

Thus, this guidance will be centred mainly in the exposure to ENMs in airborne form, able to be breathed in by workers. The size of the particles determines how much is inhaled and where they are deposited within the respiratory system (Figure 3).

Although it could be though that the smaller the particle size, the worst, it is stated that paticles with sizes around 0.3 µm are the Most Penetrating Particle Size (MPPS), since diffusion predominates below the 0.1 µm diameter, while impaction and interception predominate above 0.4 µm. In between, near 0.3 µm, both diffusion and interception are comparatively inefficient.

Though, there is a lack of international consensus about which measurement parameters (solubility, size, surface area, morphology and composition, degree of agglomeration/aggregation, surface modifications or reactivity, number concentration, and/or mass) provide the most reliable metrics (6). Particle number concentrations and particle number size distributions are the most commonly used metrics. However, the surface area per unit increases exponentially as the size decreases (Figure 4) and it starts showing new or stronger properties which have not been observed at greater sizes, but also greater reactivity, which could increase the hazards of the nanomaterial. Therefore, **it is the surface area and not particle size that is the defining metric that controls toxicological interaction** (10; 11).

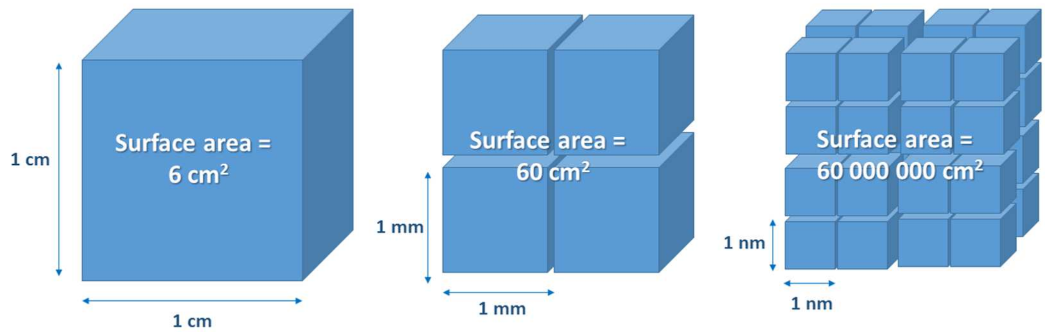



Figure 4. **E**ffect of the increased surface area provided by nanostructured materials.

Hence, a very important aspect to be considered when assessing the exposure to ENPs is the **selection of appropriate metrics and measurement strategies** to quantify the levels of release and/or exposure in the workplace and obtain reliable and interpretable data.

For this purpose, this guidance includes a number of procedures, instrumentation and sampling strategies for determining whether a release and potential exposure to engineered nanomaterials occur in the workplace. The data recompiled within this document will be accessible on line via the REACHnano Help Desk Inventory, developed under the framework of the REACHnano project.

## 3. Methodology to Measure the Exposure to Engineered Nanomaterials in the Workplace

*Accurate determination of the exposure is key to understand and* integrate an approach for Engineered NanoParticle Risk Assessment (ENPRA) approach based on the Exposure-Dose-Response Paradigm (Figure 5). This paradigm states that *exposure to ENP of different physico-chemical characteristics is likely to lead to their distribution beyond the portal-of-entry organ to other body systems. The cumulative dose in a target organ will eventually lead to an adverse response in a dose-response manner.*

Exposure can be measured directly, but is more commonly estimated indirectly through consideration of measured concentrations in the environment, consideration of models of chemical transport and fate in the environment, and estimates of human intake over time.

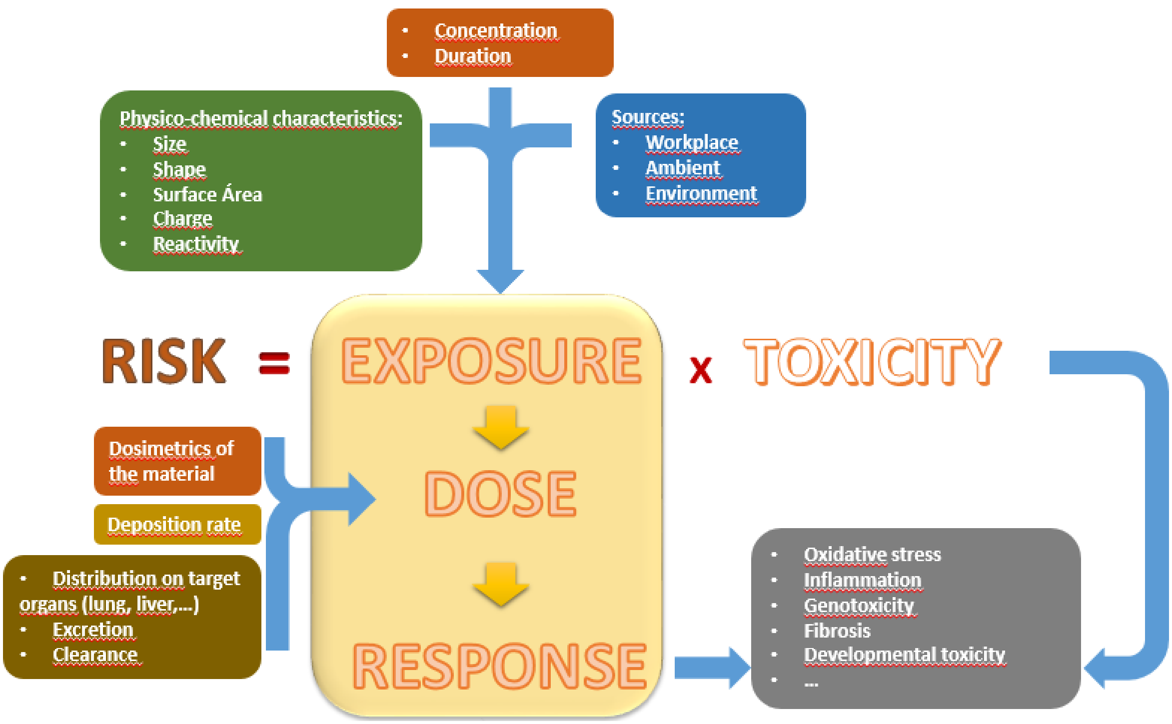



Figure 5: Flowchart of the risk assessment and the Exposure – Dose – Response paradigm.

In relation to the measurement strategies, several approaches to achieve a quantitative assessment have been proposed and discussed by relevant organizations such as the US National Institute for Occupational Safety and Health (NIOSH) or the partnership for European Research in Occupational Safety and Health (PEROSH).

The current methodology in the new EU regulatory framework REACH is based on a tiered approach named **NEAT, Nanoparticles Emission Assessment Technique** (7; 8; 12), where information is collected in each successive tier at more detailed level in order to reduce the uncertainty in the measurements.

This approach consists of a conservative first tier, involving a preliminary study of the material streams, the plant and ES identification (apparatus, equipment and machinery used), plant operations, operational conditions, RMMs and grouped together operations where exposure is likely to be similar, followed by a more realistic second tier, performed on field with portable direct-reading instrumentation placed at source-specific and close to the breathing zone (Figure 6).

There is a wide range of exposure estimation models that can be used under REACH to obtain an initial valuation of exposure based on conservative or worst case exposure conditions. This estimation is usually englobed as Tier 1 estimation. A higher Tier estimation (Tier 2) can be made using more sophisticated and detailed models and devices, although these higher Tier assessments are meant to be carried out by experienced assessor.

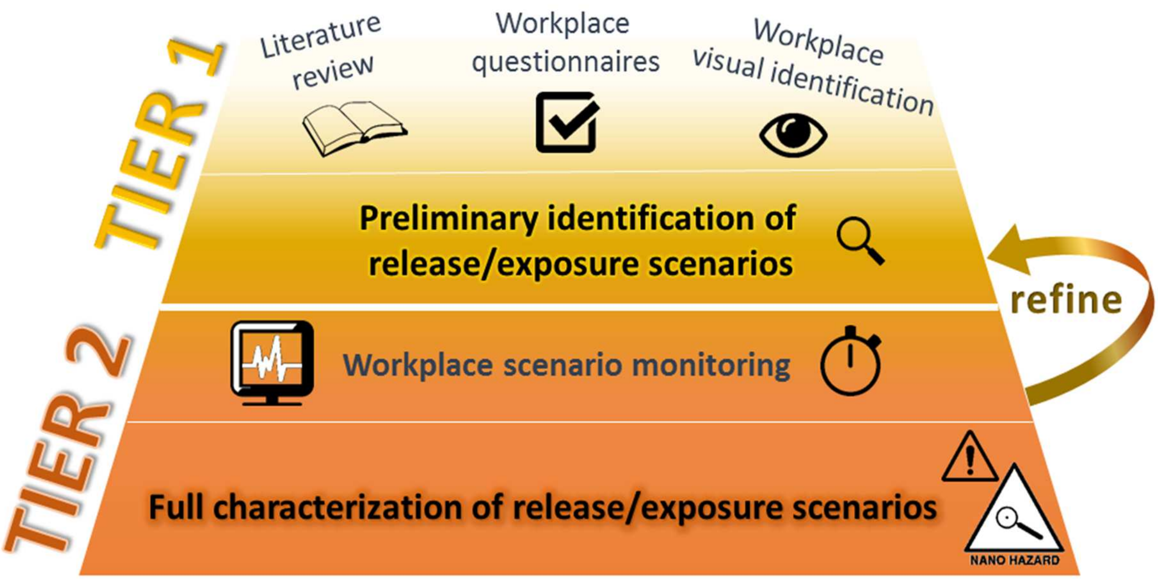



Figure 6: NEAT (Nanoparticles Emission Assessment Technique) tiered approach used.

In general, all of the approaches are based on four main steps:

TIER 1

1) **Identification of the potential sources of emission.**
2) **Definition of the measurement strategy, including instrumentation and metrics.**

TIER 2

3) **Evaluation and characterization of the background /activity levels of ENPs, describing sources of ENPs and characteristics.**
4) **Data processing.**

Each of the steps above will be described in detail in the following, providing the key subjects to perform a precise first estimation of the exposure to workers through the air ways.

### 3.1 Identification of Potential Exposure Scenarios

To assess exposure is key to identify and quantify the Exposure Scenarios (ES) of interest by defining general parameters such as:

- the exposure *situations* (occupational, environmental, consumer);
- the *route* of exposure (inhalation, ingestion, dermal);
- the *extent* of exposure (the level, duration and frequency);
- the *population* exposed.

**An Exposure *Scenario* describes the conditions in which an exposure event which occurs within a setting**, affecting a certain route, at a certain extent, for an individual or a subgroup within the exposed population.

The identification of exposure scenarios for ENMs is one of the main research priorities within nanosafety worldwide due to the need of harmonized, transferrable and effective data for decision making process (1).

Different studies (13; 14) deal with the need for adapting the information requirements necessary to assess the exposure and propose a minimum set of items that should be reported for all ENM exposure studies, drafted in Table 1.

Once the exposure scenarios are identified (Tier 1), the released ENM must be quantified and characterized in situ through experimental techniques (Tier 2) and, when needed, refining the ES defined in the previous approach.

Table 1. Standard format of a final ES for communication (14)

| Exposure Scenario Section | | Description |
|---|---|---|
| 1 | Short title of the exposure scenario | Short title and included processes explanation using the use descriptor system of REACH. Describes which uses and activities with a substance are covered in the exposure scenario |
| 2 | Processes and activities covered by the exposure scenario | |
| Operational conditions of use | | |
| 3 | Duration and frequency of use | Any action, use of tool or parameter state that prevails during manufacture or use of a substance (either in a pure state or in a mixture) that as a side effect might have an impact on exposure of humans and / or the environment. |
| 4.1 | Physical form of substance or mixture; surface to volume ratio of articles | |
| 4.2 | Concentration of substance in mixture or article | |
| 4.3 | Amount used per time or activity | Gas, liquid, powder, granules, massive solids; Surface area per amount of article containing the substance (if applicable); |
| 5 | Other relevant operational conditions of use | Temperature, pH, mechanical energy input; capacity of receiving environment (e.g. water flow in sewage/river; room volume x ventilation rate); wear and tear with regard to articles (if applicable); conditions related to service-life-time of articles (if applicable). |
| Risk management measures | | |
| 6.1 | Risk management measures related to human health | Any action, use of tool, change of parameter state that is introduced during manufacture or use of a substance (either in a pure state or in a mixture) in order to prevent, control, or reduce exposure of humans and / or the environment |
| 6.2 | Risk management measures related to environment | |
| 7 | Waste management measures | |

## 3.2 Sampling Strategy

Regarding the exposure assessment for workers, according to (15), the exposure assessment should preferably be based on **quantitative measurements** of the levels due to the lack of validated modelling tools for nanomaterial exposure, to support the risk assessment. If possible, field measurement data are currently preferred, and the assessment should follow a multi-metric approach. The use of qualitative approaches is allowed to support measured or estimated exposure data.

Among the models, one of the most widely used is the **Near Field - Far Field (NF-FF) deterministic model** (16) due to its reliability predicting occupational exposures. It was not specifically recommended by ECHA but may fall within their Tier 2 requirements.

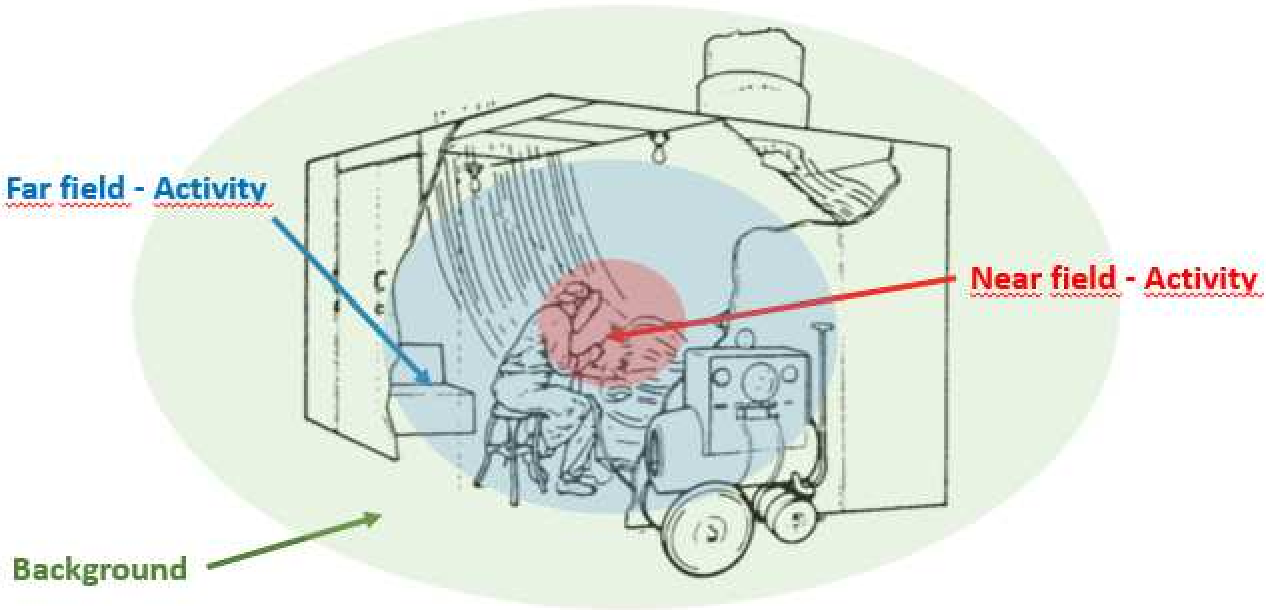



Figure 8: The Near Field – Far Field model, conceived as a 'box within a box'.

The method divides the workplace in two zones: the **NF encompasses the immediate work station and breathing zone of the worker** and the **FF is defined by the size of the room or the area where the work is performed** (17), between 1.5 to 3 m from the source (Fig. 8). It can best be described visually as a 'box within a box', where the source is located in the NF and subsequently disperses into the FF, being followed by a decay period.

For a complete assessment of the exposure in the workplace area, indoor concentration during the activity must be compared with the concentration either outdoors or during cease of activity, known as **background**. This value will help to:

- elucidate the origin and composition of the emissions (material related or environmental related),
- locate nanoparticle emission sources,
- implement corrective actions to repair,
- remove or remediate the source.

Ideally, the duration of the sampling is either **the duration of the specific process or the duration of a workday journey,** although in the end it will depend on several factors, and shorter samples can be representative enough of the exposure concentrations.

Apart from the sources and the possible release points, it is likewise determinant to locate the EC at the workplace, such as Local Exhaust Ventilation (LEV) systems (capturing hoods, enclosing hoods …) or other ventilation items, like windows, doors or air conditioned. As well, the volume of the room, numbers of people working at the same time and temperature and humidity conditions could contribute to the final exposure to the nanomaterial.

A sample form to collect the data is provided in **Appendix A**, where the main characteristics to be noted in a potential exposure scenario are listed. Description of data analysis, including the difference between background and activity and how this was calculated, whether and how peaks were addressed, and whether and how data were averaged are crucial for a qualitative assessment describing how representative the measurements are for personal exposure.

### 3.3 Instrumentation

The development of adequate instrumentation has been paid much attention in the last few years. In general, instruments can be divided in two classes: **in situ (real-time)** and **extractive (offline)**, where a sample volume of the gas is removed from its environment and transported to a location where the measurement is made.

A suite of real-time devices is already available, including portable and non-portable instruments that monitor ENPs in quasi real-time to perform temporal and spatial analysis of particle concentrations and sizes during production, maintenance and handling of ENMs.

The most employed devices are based in different physical principles (Fig. 7), such as:

- Optical instruments generally measure light scattered by the particles (Fig. 7-a), like portable optical particle sizers (OPS) in the size range of 0.3 to 10 µm
- Electrical instruments, who provide a known charge distribution to the nanoparticles to measure its electrical properties associated to their size (Fig. 7-b) and whose sensibility depends on the time resolution needed, such as the SMPS-Scanning Mobility Particle Sizer (< 30 s) or the FMPS-Fast Mobility Particle Sizer (1 s).
- Condensation or aggregation, such as the portable Condensation Particle Counters (CPCs), which measure in the size range of 10 to 1000 nm and work by growing individual particles with a gas or vapour to count them easier (Fig. 7-d).
- Impaction or centrifugation of nanoparticles, taking advantage of their inertial properties who depend on their size and mass. Some examples are cyclones or impactors, who can collect or remove particles from a given size range (Fig. 7-c).

Apart from the direct reading instruments, the collection of air samples in adequate filter media is necessary to determine the chemical composition of the airborne ENPs, because **particle classifiers are generally insensitive to particle source or composition**, being complicated to differentiate between incidental and process-related nanomaterials.

The combined use of these instruments will provide valuable information on the levels of release and exposure to ENPs, including particle number concentration (particles/$cm^3$), size distribution (dN/dlogDp) and mass distribution (mg/$cm^3$) or surface area ($\mu m^2/cm^3$), all relevant metrics for risk assessment.

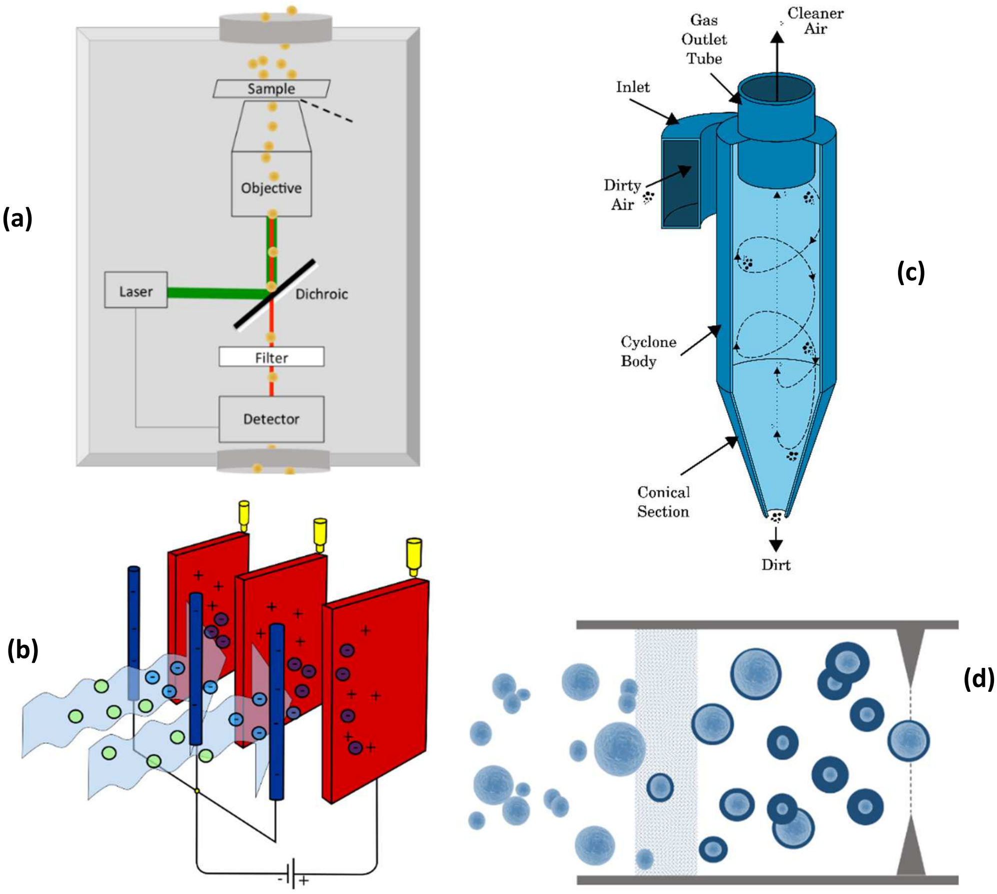



Figure 7: Illustration of some of the different physical principles of the instrumentation to measure ENMs: (a) light scattering, (b) electrostatic precipitation, (c) vortex centrifugation, (d) condensation.

These data must be complemented with the by off-line analysis of the filters, using techniques such as inductively coupled plasma-mass spectrometry (ICP-MS), energy dispersive X-ray fluorescence (ED-XRF), atomic force microscopy (AFM), electron microscopy (EM), and X-ray diffraction (XRD). To this end, appropriate air sampling filter media must be selected depending on the type of ENM and desired analytical information. In this sense, traditional open-faced cassettes (37 mm) are normally used.  As a resume, Table 2 (18) describes the main types of instruments currently available along with the metric in which they normally measure.

Exposure, as well as release measurements of ENMs, represent a difficult task due to temporal and spatial variability in both particle size distribution and number concentration throughout time because of aggregation, masking by background or deposition of the particles. Measurements require not just sophisticated instruments, but especially compliance with best practices protocols (19). The more information is gained, the better characterized will be the environment to which the worker is exposed. However, due to the limited possibility of having several types of instrumentation, it has to be planned forehand the data acquisition strategy and the parameters to be measured to complete the characterization of the nanomaterial.

Table 2. Main instruments available for exposure assessment and metric measured (reproduced from (18))

| METRICS | DEVICE | REMARKS |
|---|---|---|
| **Mass** | Size selective personal sampler | No current devices offer a cut point of 100 nm. Off-line gravimetric or chemical detection is necessary.<br>Mass may also be derived from size distribution measurements (see below). |
| | Size selective static sampler | The only devices offering a cut point around 100 nm are cascade impactors. |
| | TEOM® | Sensitive real-time monitors such as the Tapered Element Oscillating Microbalance (TEOM®) may be useable to measure nanoaerosol mass concentration on-line, with a suitable size selective inlet. |
| | SMPS | Real time size-selective (mobility diameter) detection of number concentration. Data may be interpreted in terms of aerosol mass concentration, only if particle shape and density are known or assumed. |
| | ELPI | Real time size-selective (aerodynamic diameter) detection of active surface-area concentration. Data may be interpreted in terms of mass concentration if particle charge and density are assumed or known.<br>Size-selected samples may be further analysed off-line. |
| **Number** | CPC | CPC (Condensation Particle Counter) provide real time number concentration measurements between their particle diameter detection limits. Without a nanoparticle pre-separator, they are not specific to the nanometre size range (no suitable pre-separators are currently available). |
| | SMPS | Real time size-selective (mobility diameter) detection of number concentration. |
| | ELPI | Real time size-selective (aerodynamic diameter) detection of active surface-area concentration. Data may be interpreted in terms of number concentration. Size-selected samples may be further analysed off-line. |
| | Optical Particle Counter | These are insensitive to particles smaller than approximately 100 nm - 300 nm in diameter, and therefore unsuitable for nanoparticle monitoring. |
| | Electron Microscopy | Off-line analysis of electron microscope samples can provide information on size-specific aerosol number concentration. |
| **Surface Area** | SMPS | Real time size-selective (mobility diameter) detection of number concentration. Data may be interpreted in terms of aerosol surface-area under certain circumstances. |

| METRICS | DEVICE | REMARKS |
|---|---|---|
| | ELPI | Real time size-selective (aerodynamic diameter) detection of active surface-area concentration. Data may be interpreted in terms of number concentration. Size-selected samples may be further analysed off-line. |
| | SMPS and ELPI used in parallel | Differences in measured aerodynamics and mobility diameters can be used to infer particle fractal dimension, which can be further used to estimate surface-area. |
| | Diffusion Charger | Real-time measurement of aerosol active surface-area. Active surface-area does not scale directly with geometric surface-area above 100 nm. Note that not all commercially available diffusion chargers have a response that scales with particle active surface-area below 100 nm. Diffusion chargers are only specific to nanoparticles if used with an appropriate inlet pre-separator |
| | Electron Microscopy | Off-line analysis of electron microscope samples can provide information on particle surface-area with respect to size. TEM analysis provides direct information on the projected area of collected particles, which may be related to geometric area for some particle shapes. |

### 3.4 Data interpretation: an example

A fictional example of a sampling plan for an extrusion process is shown in Fig. 9. The scenario is a mid-scale plant where nanomaterials such as metal oxides or nanoclays were added to composites in order to improve the performance of the original materials, used for packaging. The study is centred in the extrusion process of a substance with added nanoparticles of $TiO2$, which provides reinforcing fillers to improve properties of UV protection and material resistance to tear.

First of all, a **complete map of the room where the process takes place is drafted**, marking the ventilation points and the total volume. The measuring devices are placed during the activity as close as possible to the sources where a potential exposure can be produced, at the same time as, when feasible, the worker will carry close to the respirable zone some of the smallest, portable devices which do not interfere with his activity with him, to gather information about the concentration able to be breathed by the worker.

The instrumentation employed was **a combination of real-time and offline instruments**: two breathing pumps with polycarbonate particle filter samplers for microscopy analysis, plus devices to characterize particle number concentration and size/mass/surface area distribution. Instruments were left measuring overnight to record the background concentration within the room when no activity was taking place.

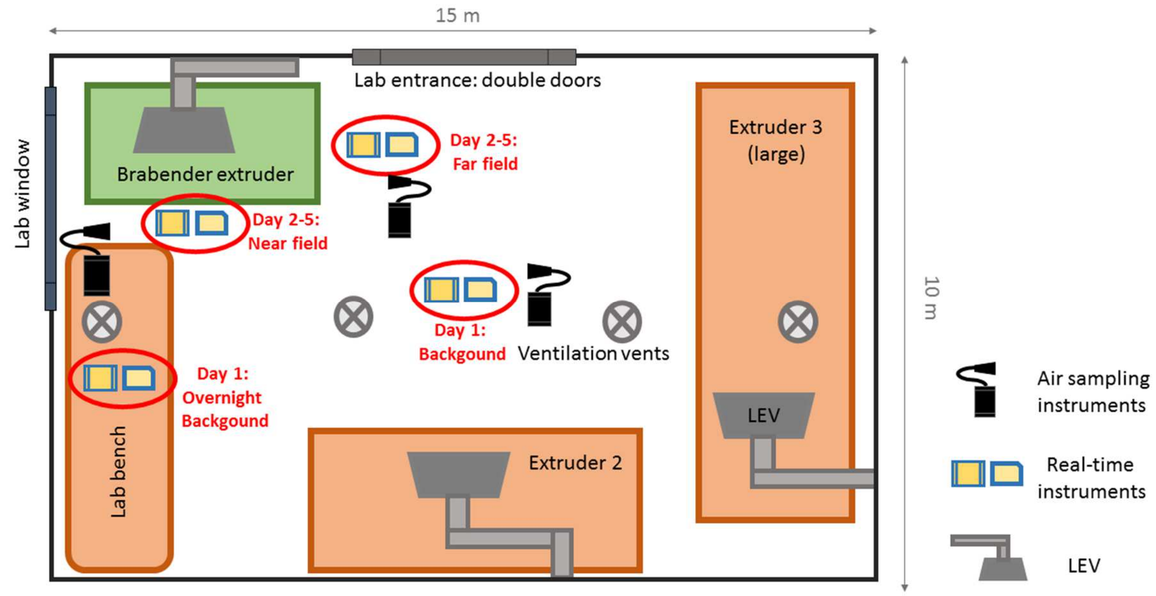



Figure 9: Example of a sampling strategy NF-FF to measure ENMs released in an extrusion machine.

An example of the real-time results can be seen in Fig. 10: it can be seen how the concentration of nanoparticles increases with the duration of the activity, to decrease at the end when ventilation systems are switched on. It is remarkable as well to see how the concentration at the FF is slightly greater than at NF, due to the spreading out of particles in the surroundings of the working area that can lead also to aggregation or agglomeration phenomena, increasing their surface area. Differences in concentrations between different devices are due to their different size ranges and measuring physical principles.

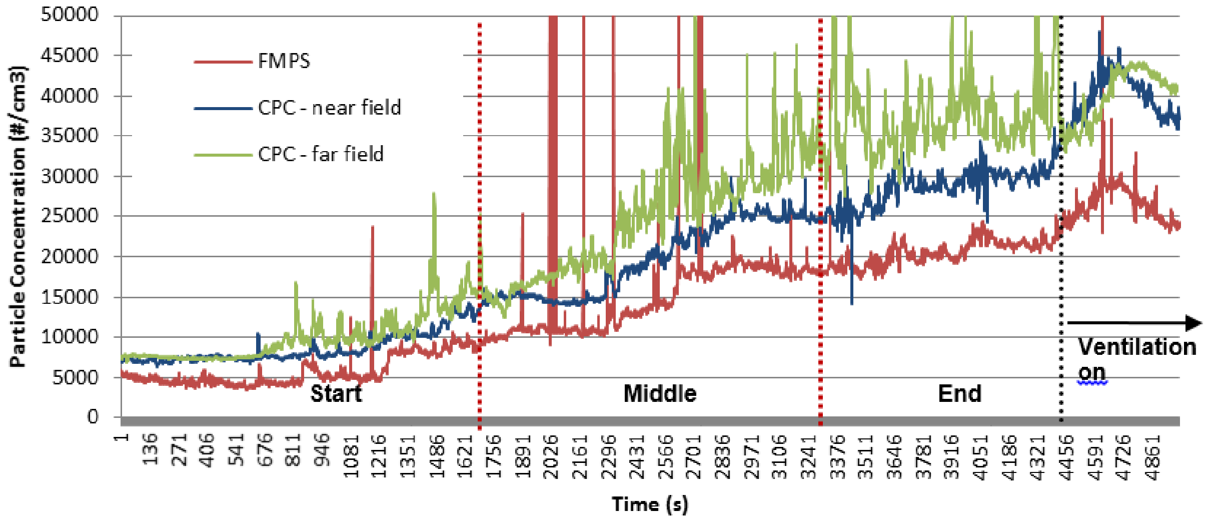



Figure 10: Results from the concentration of the previous example.

These results must be complemented in any case with information about the size or mass distribution of the particles and its composition, to reveal the real hazard potential of the ENMs exposure. In Figure 11 it can be seen the particle size distribution along time measured in one of the activity tasks.

Nanoparticles of about 50 nm are released, although with time passing on they agglomerate or aggregate forming bigger distribution of particles, up to near 350 nm.

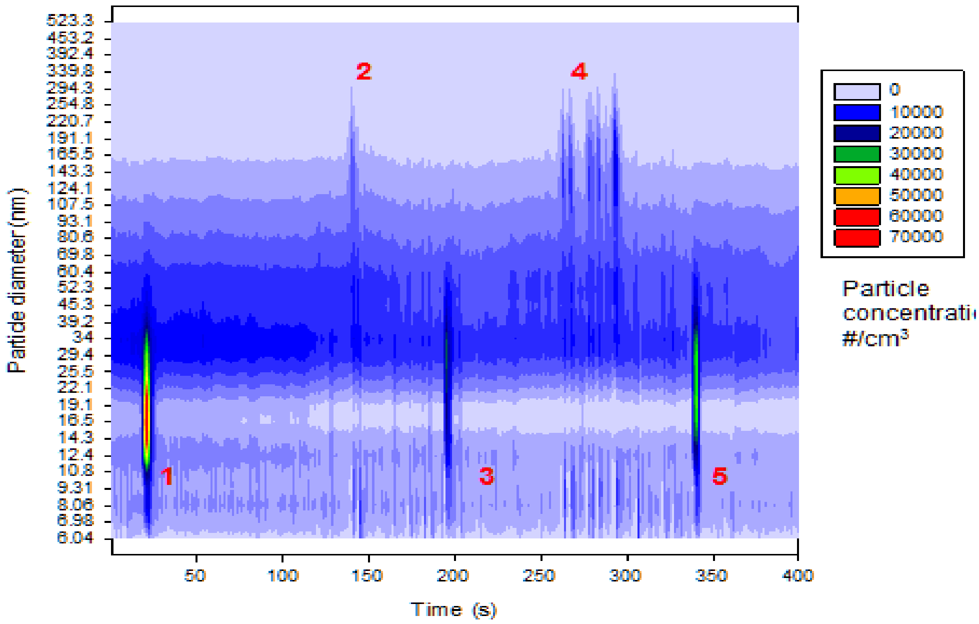



Figure 11. Particle size distribution during the extrusion process.

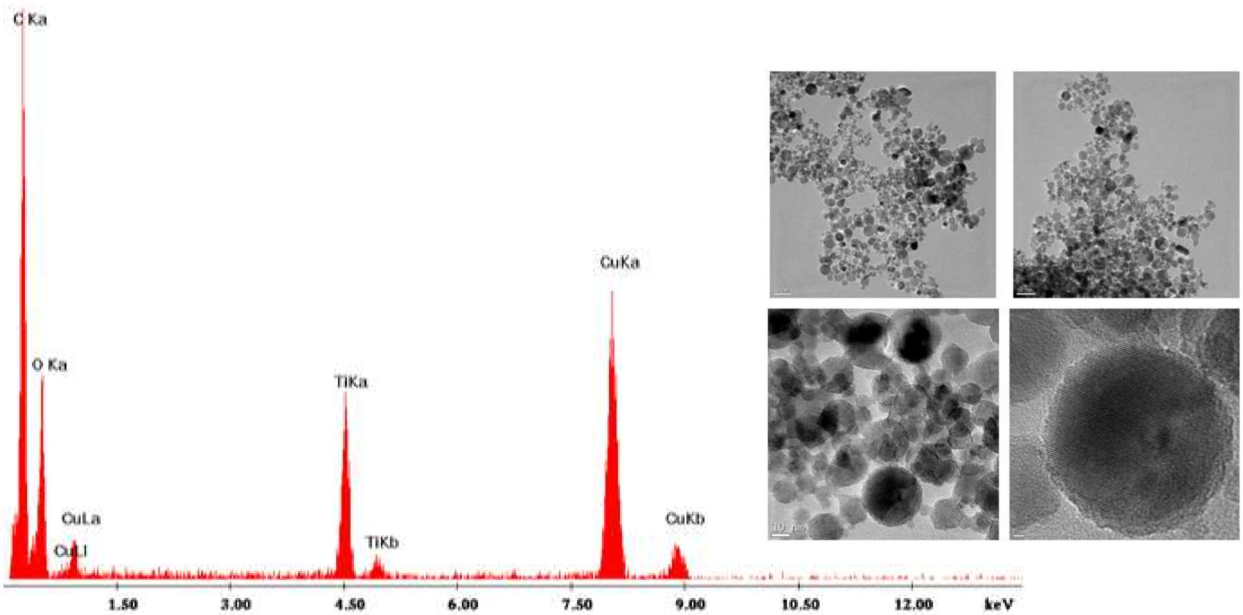



Figure 12. High Resolution TEM images and EDX spectrum of the $TiO_2$ nanoparticles collected during the process.

However, is fundamental to characterize the origin and composition of the particles, thus the filters carried by workers during the process are analysed by microscopy. A High-resolution Transmission Electron Microscopy (HR-TEM) image from the released nanoparticles can be seen in Fig. 12. Particles are perfectly spherical and highly crystalline, with sizes around 50 nm. This information will be useful to calculate the surface area from the concentration measurements.

Likewise, the Energy-Dispersive X-ray spectroscopy (EDX) from Fig. 12 shows the chemical composition of the captured particles. In the spectrum appear Ti and O as elements in an approximate atomic ratio 1:2, which is in fact $TiO_2$. Only the presence of Ti and O (in the form of metal oxide) and C and Cu from the grid is detected, thus we can **confirm the presence of the working nanomaterial in the airborne nanoparticles released to which the worker is exposed**.

Thus, from the recorded data and posterior analysis, it can be concluded that during the extrusion process **there is a significant exposure to ENMs, which can be considerably reduced when engineering controls such as ventilation hoods are connected**. However, to avoid any further risk, workers should be wearing Respiratory Protective Equipment such as half masks with at least FFP2 filters.

## 4. Summary

There are currently no exposure limits specific to ENM nor any national or international consensus standards on measurement techniques for nanomaterials in the workplace. However, facilities engaged in the production and use of these ENMs have expressed an interest in learning whether the potential for worker exposure exists. To assist with answering this question, this guidance shows the basic steps necessary to monitor in a first approach the exposure to airborne ENMs.

There are several approaches, being the most common the NEAT tiered approach in combination with the NF-FF measurements. The baseline for the exposure assessment is based on four main steps:

1 **Identification of the potential sources of emission**

2 **Definition of the measurement strategy, instrumentation and metrics**

3 **Evaluation and characterization of background and source levels of ENPs considering the workplace characteristics**

4 **Data processing and interpretation**

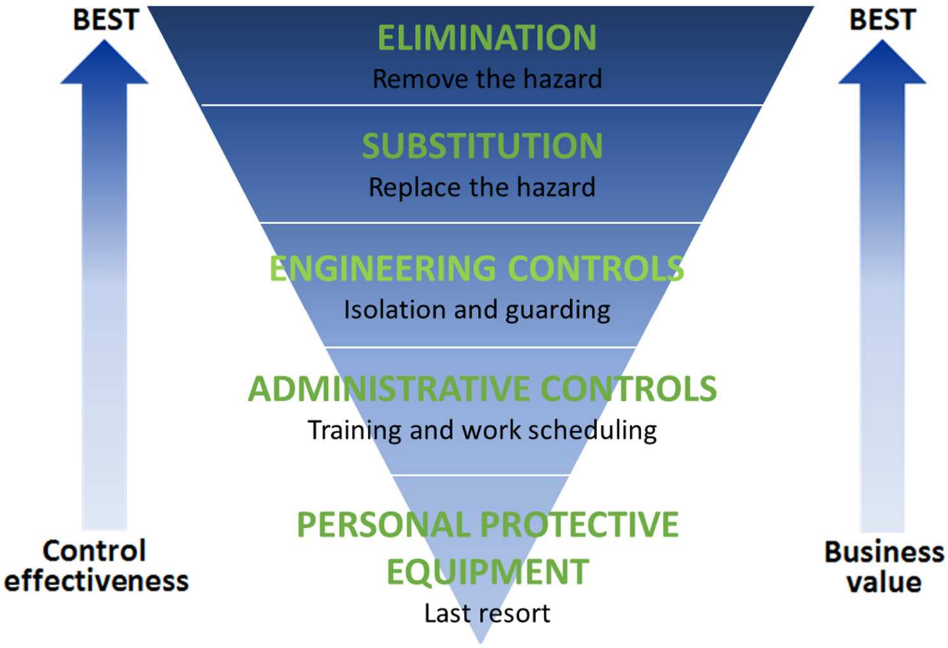



Figure 13: Hierarchy of Risk Management Measures to fulfil when a hazard ENM is identified.

Once the data is analysed and conclusions extracted, the necessary mitigation measures must be taken into account to avoid the hazard provoked by the ENM. These measures, known as Risk Management Measures (RMM, Figure 13), stablish the procedures to follow when a threat to the health or the environment is identified.

Since this guidance is focused on the airborne exposure to ENMs, the mainly points to measure are the breathing areas of the worker, being of critical importance the ventilation and contention controls present at the workplace. Instrumentation able to measure airborne nanoparticles must be carefully selected, in order to cover the maximum information possible regarding the environment at the workplace.

## 5. References

1. **Savolainen et al.** *Nanosafety in Europe 2015-2025.* s.l. : Finnish Institute of Occupational Health / EU NanoSafety Cluster, 2013.

2. **Kumar et al.** *Manual on Critical Issues in Nanotechnology R&D Management: An Asia-Pacific Perspective.* s.l. : APCTT-ESCAP, 2013.

3. *Exposure to manufactured nanoparticles in different workplaces.* **Brouwer, Derk.** 2010, Toxicology , Vol. 269, pp. 120-127.

4. *Engineered nanomaterials: exposures, hazards, and risk prevention.* **RA, Yokel.** s.l. : Nanotechnology Safety and Health Research Program, 2011, Journal of Occupational Medicine and Toxicology, Vol. 6:7.

5. *Nanoparticles - known and unknown health risks.* **Hoet PHM, Brüske-Hohlfeld I, Salata O.** 12-26, s.l. : J Nanobiotechnol, 2004, Vol. 2.

6. *Spatial and temporal variability of incidental nanoparticles in indoor workplaces: impact on the characterization of point source exposures.* **Jianjun Niu et al.** 201517, Environmental Science: Processes and Impacts, pp. 98-109.

7. *Nanoparticle Emission Assessment Technique (NEAT) for the Identification and Measurement of Potential Inhalation Exposure to Engineered Nanomaterials — Part A.* **Methner, M; et al.** 127-132, s.l. : Journal of Occupational and Environmental Hygiene, 2010, Vol. 7.

8. *Nanoparticle Emission Assessment Technique (NEAT) for the Identification and Measurement of Potential Inhalation Exposure to Engineered Nanomaterials —Part B: Results from 12 Field Studies.* **Methner, M; et al.** 163-176, s.l. : Journal of Occupational and Environmental Hygiene, 2010, Vol. 7.

9. **Karjalainen; A. et al.** *Scaffold D.1.2.Background information on exposure, use, and hazard of manufactured nanomaterials in the construction sector.* 2012.

10. *ECOTOXICITY OF SILICA NANOPARTICLES TO THE GREEN ALGA PSEUDOKIRCHNERIELLA SUBCAPITATA.* **K. Van Hoecke et al.** 9, s.l. : Environmental Toxicology and Chemistry, 2008, Vol. 27. 1948 - 1957.

11. *Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles.* **Oberdörster G, Oberdörster E, Oberdörster J.** 823-839, s.l. : Environ Health Perspect, 2005a, Vol. 113.

12. **NIOSH Publication No. 2009-125.** *Approaches to Safe Nanotechnology Managing the Health and Safety Concerns Associated with Engineered Nanomaterials.*

13. *Limitations and information needs for engineered nanomaterial-specific exposure estimation and scenarios: recommendations for improved reporting practices.* **K, Clarck, et al.** 970, s.l. : Journal of nanoparticle research, 2012, Vol. 14.

14. **ECHA.** Guidance on information requirements and chemical safety assessment. s.l. : European Chemicals Agency , 2012.

15. *Human health and environmental exposure assessment and risk characterisation of nanomaterials: Best practice for REACH registrants.* **Agency, European Chemicals.** Helsinki : Third GAARN meeting, 30 September 2013.

16. *A comparison study using a mathematical model and actual exposure monitoring for estimating solvent exposures during the disassembly of metal parts.* **Spencer JW, Plisko MJ.** 253-259, s.l. : J Occup Environ Hyg, 2007, Vol. 4.

17. *Hemeon's Plant & Process .* **DJ, Burton.** s.l. : Boca Raton: Lewis Publishers, 1999.

18. **ISO/TR 27628:2007.** *Workplace atmospheres - Ultrafine, nanoparticle and nano-structured aerosols - Inhalation exposure characterization and assessment.*

19. *Building exposure scenarios for safety management of engineered nanomaterials.* **Sikorová L, Van Tongeren M, Danihelka P, Sánchez Jiménez A, Bernatíková S. .** Brno, Czech Republic : Nanocon 2014, Nov 5th – 7 th 2014.

20. *Do nanoparticles interfere with human health? .* **Brüske-Hohlfeld I, Peters A, Wichmann H-E.** 21-23, s.l. : GAIA, 2005, Vol. 14.

21. **Asbach, C. et al.** *NanoGEM: Standard Operation Procedures for assessing exposure to nanomaterials, following a tiered approach."Tiered Approach for the assessment of exposure to airborne nanoobjects in workplaces.* 2012.

22. *Recommendations for characterizing potential emissions and exposure to aerosols released from nanomaterials in workplace operations.* **Witschger, O et al. .** 2012, Hyg. Secur. Trav, Vol. 226, pp. 41-55.

23. *Conceptual model for assessment of inhalation exposure to manufactured nanoparticles. .* **Schneider, T., Brouwer, D. H., Koponen, I. K. et al.** 1-14, s.l. : Journal of Exposure Science and Environmental Epidemiology, 2011.

# 6. Appendix

## Exposure Assessment Form

| Information on Nanomaterial | |
|---|---|
| Description of physical and chemical form of the ENM used | Chemical composition, including surface treatment/ modification |
| | |
| | Size distribution (including dimensions for fibers) |
| | |
| | Surface area |
| | |
| | Details on the matrix surrounding the ENM, if any<br><br>(e.g. form of matrix: powder, liquid, solid, granules or amount of ENM used in the matrix) |
| | |
| **Information on Process** | |
| Description of the process and all activities included | Activities performed |
| | |
| | Typical duration and frequency of these activities |
| | |
| | Type of enclosure of process: if enclosed, provide frequency and duration of opening for maintenance, quality control and/or other manual operations |
| | |
| | Total volume of ENM used on site |
| | |
| | Number of workers involved |
| | |

| | | | | |
|---|---|---|---|---|
| Description of site | Room size | T (ºC) | HR (%) | Wind speed (m/s) |
| | | | | |
| | Windows and entrance doors (number, location, size, frequency of use…) | | | |
| | | | | |
| Risk Management Measures (RMM) | Presence of LEVs | | | |
| | | | | |
| | Use of PPE | | | |
| | | | | |
| | Other measures to prevent human exposure or environmental release (e.g., administrative controls, additional engineering controls) | | | |
| | | | | |
| **Sampling and data analysis strategy** | | | | |
| Location of samplers | | Near Field | Far Field | Background |
| Types of samplers available | Real-time | | | |
| | Extractive | | | |
| Duration / repetition of samples | | | | |
| | | | | |
| Description of activities associated with each sample | 1. | | | |
| | | | | |
| | 2. | | | |
| | | | | |
| | 3. | | | |
| | | | | |

| | |
|---|---|
| | 4. |
| | |
| | 5. |
| | |
| | |
| | |
| | |
| | |
| **REMARKS:** | |
| | |

## Abbreviations And Acronyms

| Acronym | Description |
|---|---|
| EC | Engineering Controls |
| ECHA | European Chemicals Agency Sited In Helsinki. |
| EDX | |
| ENMs | Engineering Nanomaterials |
| ENPRA | Engineered Nanoparticle Risk Assessment |
| ES | Exposure Scenario |
| HR-TEM | High-resolution Transmission Electron Microscopy |
| NEAT | Nanoparticles Emission Assessment Technique |
| NF-FF | Near Field – Far Field Measuring Strategy |
| NIOSH | National Institute For Occupational Safety And Health |
| PEROSH | Partnership For European Research In Occupational Safety And Health |
| REACH | Registration, Evaluation, Authorisation and Restriction of Chemicals |
| RMM | Risk Managment Measure |

## List of tables



## List of Figures

## Further Information

Packaging, Transport and logistics research center

Contact: Carlos Fito

email: *cfito@itene.com*

Location: SPAIN     Website URL: http://www.itene.com

LEITAT Technological Centre

Contact: Natalia Fuentes

email: *nfuentes@leitat.org*

Location: SPAIN     Website URL: http://www.leitat.org

Nanotechnology Industries Association

Contact: David Carlander

email: *david.carlander@nanotechia.org*

Location: BELGIUM     Website URL: http://nanotechia.org/

INVASSAT. Instituto valenciano de seguridad y salud en el trabajo

Contact: Esteban Santamaría

email: *santamaria_est@gva.es*

Location: SPAIN   Website URL: http://www.invassat.gva.es/

---

*http://www.lifereachnano.eu - http://tools.lifereachnano.eu*

Contents Manager
ITENE - Packaging, Transport and logistics research center
Albert Einstein, 1. 46980 Paterna. Valencia (Spain)
E-mail: *cfito@itene.com*

**REACHnano is partly funded by the European Commission Life+ with grant agreement LIFE11 ENV/ES/549**