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Nanotechnologies

Part 3: Guide to assessing airborne exposure in occupational settings relevant to nanomaterials

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Foreword

Publishing information

This Published Document is published by BSI and came into effect on 30 November 2010.

The initial drafting of this Published Document was produced in association with BIS as part of their ongoing programme of support for standardization.

PD 6699, *Nanotechnologies*, now comprises the following parts:

Part 1: *Good practice guide for specifying manufactured nanomaterials*;

Part 2: *Guide to safe handling and disposal of manufactured nanomaterials*;

Part 3: *Guide to assessing airborne exposure in occupational settings relevant to nanomaterials.*

Use of this document

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The word "should" is used to express recommendations of this Published Document. The word "may" is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the clause. The word "can" is used to express possibility, e.g. a consequence of an action or an event.

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0 Introduction

By almost any measure, the growth of nanotechnology as a scientific and technological activity over the last ten years has been enormous. Indicators include almost exponential growth in scientific papers published, patent applications lodged, investments by national authorities and private industry, number of people employed in the area and revenue generated. This has led to the development and production of many new forms of materials at the nanoscale, with a range of divergent properties when compared to the same materials at a larger scale. Well-known examples include materials like carbon nanotubes (CNT), which have greatly enhanced strength and conductivity when compared to other forms of carbon, and quantum dots, which emit light at frequencies which depend on their particle size. These new nanomaterials are synthesized in a wide range of production processes and, in turn, lead to a wide range of applications and processes in which they can be used.

Against this background, concerns have been expressed about the potential risk to the health of individuals involved in the manufacture and use of these materials and to the environment (RS/RAEng 2004 [1]). A full understanding of the potential risks of such materials when manufactured or used requires an understanding of the intrinsic toxicity of the materials and the extent to which people (or the environment) are exposed. Since publication of the Royal Society/Royal Academy of Engineering report [1] in 2004, there has been a large increase in research activity focused on identifying, categorizing and quantifying the potential risks associated with a wide range of new nanomaterials [2]. The focus has been largely on the toxicological aspects, with, to date, less effort on understanding and quantifying exposure. However, recent studies are contributing to increased understanding of the instruments used and their limitations, and how these can be used in combination to provide better quantification of exposure [3],[4]. As yet, though, there is no consensus on which methods are appropriate for each situation, how they are to be applied in detail, and what the limitations of these methods might be.

1 Scope

This Published Document gives guidance on the development and implementation of plans and strategies for the assessment of exposure by inhalation of nanomaterials, based on an understanding of the nature of the exposure and the capabilities and limitations of exposure measurement instrumentation. It is applicable to all workplace settings in which nano-objects, including nanoparticles and nanotubes, are manufactured, processed or used. Sources of other data and information are also provided.

The Published Document describes a structured, step-by-step approach to exposure assessment which takes into account the purpose, the type of information needed, and the usefulness and limitations of the various approaches for exposure assessment for different types of nanomaterials, and provides a rationale for method selection.

This Published Document is intended to compliment the development and take-up of new nanotechnology-based materials in UK industry by providing manufacturers and users of these materials with effective strategies for assessing worker exposure to airborne nanomaterials.

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Given the emergent nature of the knowledge base in this area, the guide is targeted at the professional user who already has some knowledge and experience of exposure assessment and occupational hygiene practice.

2 Terms and definitions

For the purposes of this Published Document, the terms and definitions given in PAS 136 apply.

NOTE The term "nanomaterials" includes nano-objects and aggregates and agglomerates of nano-objects, including where they are embedded within a matrix.

3 Abbreviations

APS	Aerodynamic particle sizer
CNT	Carbon nanotube
CPC	Condensation particle counter
DMA	Differential mobility analyser
EDX	Energy dispersive x-ray analysis
ELPI	Electrical low pressure impactor
FMPS	Fast mobility particle counter
HARN	High aspect ratio nano-objects
ICP-MS	Inductively coupled plasma mass spectroscopy
ICPM-OES	Inductively coupled plasma optical emission spectrometry
OPC	Optical particle counter
NEAT	Nanoparticle emission assessment technique
NIOSH	National Institute for Occupational Safety and Health
NM	Nanomaterial
NP	Nanoparticle
PCOM	Phase contrast optical microscopy
SEM	Scanning electron microscope
SMPS	Scanning mobility particle sizer
TEM	Transmission electron microscope

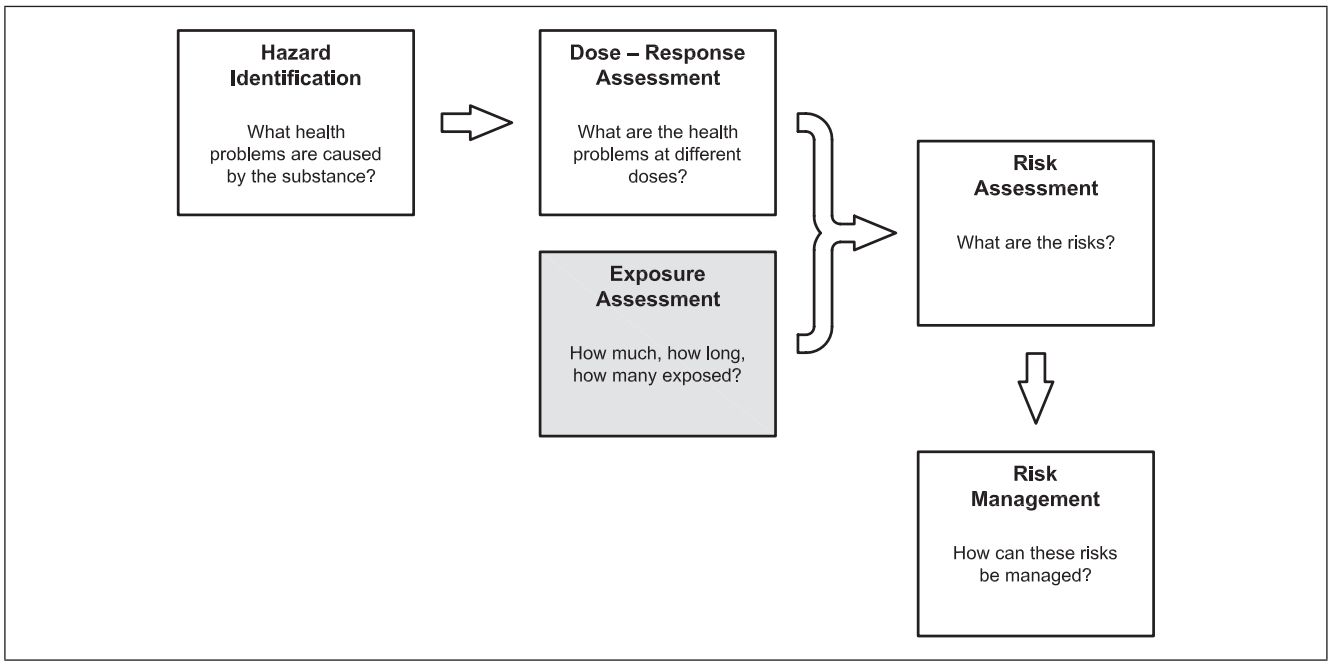
4 Exposure assessment generic

4.1 Defining exposure

The risk to the health of an individual or a population arising from exposure to a chemical agent is generally considered to be a function of the intrinsic harmfulness of the chemical (its toxicity) and the dose (amount) which accumulates in the specific biological compartment (e.g. the lungs). In an occupational context it is difficult to quantify the dose, specifically in the case of insoluble particulates. In order to quantify and manage the risks, it is usual to use exposure as a proxy for dose. Knowledge of plausible exposure levels and duration

enables realistic interpretation of dose-response relationships. Knowledge and control of exposure is critical in risk assessment and management, as indicated in Figure 1.

Figure 1 **The risk assessment paradigm relating hazard, exposure and risk**



Critical questions in relation to exposure are: how much, how long and how many people are exposed? Thus, exposure is usually measured (quantified or assessed) in terms of its intensity (concentration) and duration (or frequency). Control of exposure (to zero) effectively removes the risks from the toxic agent. Without exposure there is no risk.

4.2 Routes of exposure

The main routes by which workers can be exposed to particles are inhalation, ingestion and dermal penetration.

a) Inhalation is considered to be the primary route by which particles suspended in air can enter the bodies of workers. Once inhaled, particles deposit in all regions of the respiratory tract. The site and extent to which particles deposit in the respiratory tract are dependent on particle size, expressed in terms of aerodynamic diameter (for particles greater than approximately 300 nm) or thermodynamic diameter for particles less than 300 nm) [1)]. Figure 2 shows the fractional deposition of inhaled particles in the nasopharyngeal, tracheo-bronchial and alveolar regions of the human respiratory tract for nasal breathing at rest, using the predictive mathematical model of the International Commission for Radiation Protection [5]. There is an increasing total deposition as particle size decreases below around 300 nm.

1) The "aerodynamic particle diameter" is the diameter of a sphere with a density of 10^3 kg·m^{-3} and the same terminal settling velocity in air as the particle of interest. The "thermodynamic particle diameter" is the diameter of a spherical particle that has the same diffusion coefficient in air as the particle of interest.

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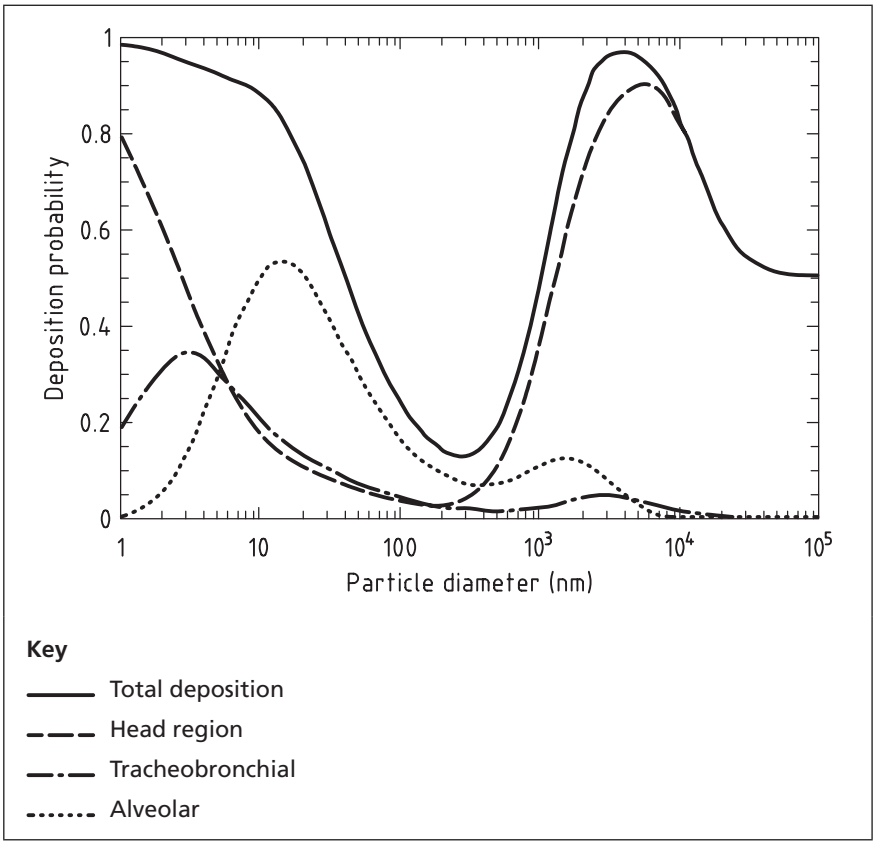
Figure 2 **Predicted total and regional deposition of particles in the human respiratory tract related to particle size, using ICRP 66 model**



b) Ingestion exposure to particles in general can arise from hand-to-mouth contact by sucking or licking a contaminated surface, or by eating contaminated food. It might also be caused by swallowing mucus containing deposited particles which has been cleared from the lung. Occupational ingestion exposure to nanomaterials has not yet been studied to any extent.

c) Dermal exposure is of increasing concern in workplaces [6]. Workers can be exposed via the skin by handling or touching materials or surfaces coated with nanomaterials. One of the challenges in managing the risks arising from dermal exposure is that protective equipment designed to prevent exposure, such as gloves, can in itself act as a reservoir of contaminant, potentially exacerbating the exposure. Currently, there is little evidence that insoluble NP depositing on the skin can penetrate the epidermis [7],[8]. However, only a few studies have been published thus far. Local effects, such as sensitization and dermatitis, have not been investigated for NP and so cannot be ruled out.

This Published Document focuses on exposure by inhalation.

4.3 Exposure metrics

In early studies which considered the health effects of inhaled particles, dust (particle) samples were collected by drawing air through a filter or other medium and subsequently analysed off-line to estimate exposure, expressed as a concentration in air. For example, in the coal industry the samples were analysed by counting particles collected on the filter under a light microscope [9]. This resulted in an estimate of exposure

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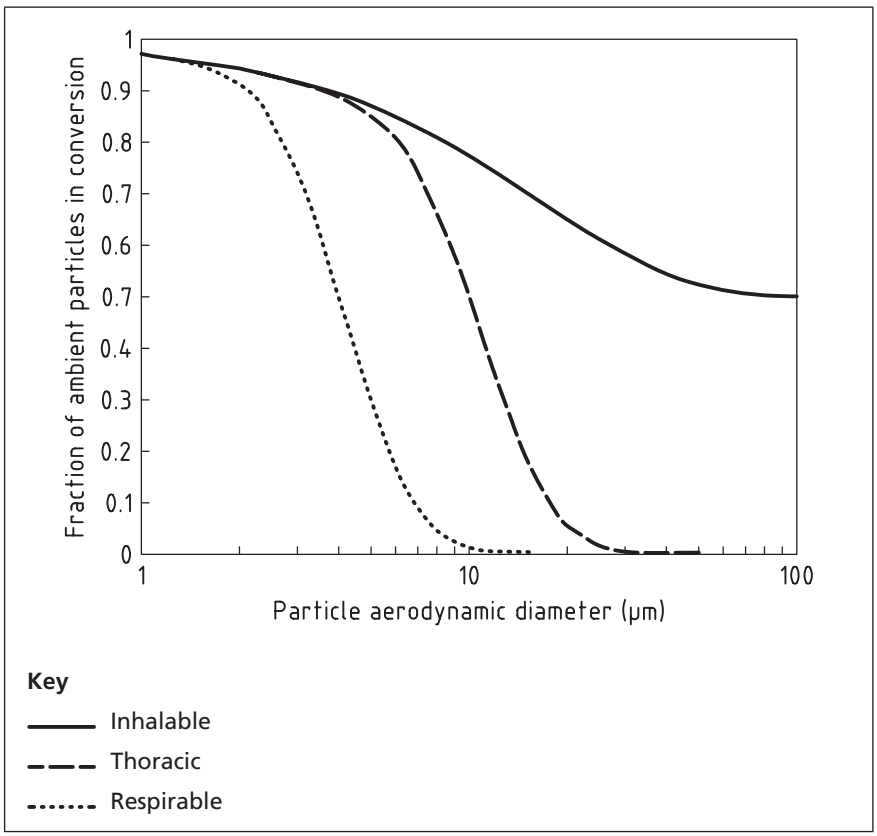
in terms of particle number concentration, expressed as number of particles per cc or per m^3 of air. Epidemiological studies in that industry later demonstrated a strong correlation between pneumoconiosis and mass concentration, typically expressed as $mg \cdot m^{-3}$. Assessment in terms of mass was less demanding and more accurate than manual counting under a microscope and so was the preferred choice. The use of workplace exposure limits (WEL), based on mass concentrations, has become the norm for measuring or regulating exposure for most hazardous chemicals and particles [10].

A further refinement of this approach involves sampling of particles based on collection of a biologically relevant aerosol fraction. In this context, biological relevance is characterized by the region of the respiratory tract to which a particle can potentially penetrate and determined as a function of particle size, measured in terms of aerodynamic diameter. Such fractions are defined as follows (ISO 7708).

- The inhalable convention: the mass fraction of total airborne particles that enters the nose or mouth during breathing.
- The thoracic convention: the mass fraction of inhaled particles that penetrate the larynx, with 50% penetration at 11.64 µm (equivalent to 10 µm when expressed as a fraction of total aerosol).
- The respirable convention: the fraction of inhaled particles that penetrate to the alveolar region of the lung, with 50% penetration at 4.25 µm (equivalent to 4 µm when expressed as a fraction of total aerosol).

The conventions are shown in Figure 3.

Figure 3 **Health-related sampling conventions for workplace aerosols (ISO 7708:1995)**



The one class of aerosols that are treated differently are fibres. Fibres have an extreme shape (aspect ratio). Their behaviour in the lungs differs substantially from many, more compact particles, and they can persist for long periods in the lungs following deposition. Exposure to fibres is not characterized in terms of averaged mass and composition, but by the number (concentration) of fibres in the air with a specific shape and composition. To assess exposure, fibres are collected on a filter and are counted by phase contrast light microscopy [11]. Only visible fibres with widths greater than 0.2 μm and less than 3 μm, a length greater than 5 μm and an aspect ratio of at least 3:1 are counted, and these are used to give an "index" of the fibre exposure. These are sometimes referred to as "regulatory" or "respirable" fibres. To count the fibres (such as asbestos) where there are also many fibres present that are not visible by light microscopy (i.e. <200 nm width), electron microscopy has been widely used, and international standards for both scanning and transmission electron microscopy are available, e.g. ISO 10312, ISO 13794.

4.4 Measurement of exposure

Particle sampling and measurement is extremely helpful in assessing exposure and risk in workplace scenarios. Measurement can be used to support various activities, including:

- assessment of personal exposure for ensuring compliance with any WEL or self-imposed (in-house) exposure standard;
- assessment of personal exposure for linking with potential adverse health effects in epidemiological studies;
- identification of emission sources;
- assessment of the effectiveness of any control measure implemented.

Each of these issues could imply different constraints on the selection of measurement approaches. For example, for epidemiological studies the currently held view is that samples collected ought to be based on personal exposure [2)]. This implies that the sampling instruments used are to be of such a size that they can be worn by the individuals (workers) participating in the study without any changes in their normal work activities and behaviour. To facilitate such a study, it is necessary for relatively large numbers of sampling instruments to be available such that estimates from large populations can be obtained.

In contrast, compliance with air quality standards for environmental pollution is based on assessments made using fixed point (static) monitors placed in predetermined positions. Here it is assumed that the concentration of pollution is largely homogenous, so exposure can be adequately assessed from measurements made with a fixed point monitor, based at some distance from the individual. The requirement for relatively few instruments, located at the fixed points, means that the constraints on size and mobility of these devices, as well as the costs, are very different from personal sampling.

[2)] Large spatial differences in aerosol concentration can occur around industrial processes and around the human body. Placing an aerosol sampler on the body, within a few cm of the mouth and nose (personal sampling), reduces errors in estimating an individual's exposure.

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Often, the quantity of interest relating to exposure cannot be measured directly (or completely) due to limitations in the analytical method, or as a result of the study design. In these cases, it is necessary to adopt a measurement strategy in which the required metric is estimated, based on what can actually be measured in practice. The early particle number-based measurements of coal dust or the measurement of fibres (see **4.3**) provide good examples of this.

5 Measurement in occupational settings relevant to nanotechnologies

5.1 Relevant sizes of particles to measure

According to the current definition of the inhalable fraction, the upper value of the aerodynamic diameter of a particle that, by convention, can be inhaled into the body is 100 µm (100 000 nm). The majority of the individual nanoparticles (between 1 nm and 100 nm) released into the air will usually be present as agglomerates. It is likely that nanoparticles will be present as agglomerates which could represent structures, such as chains, several times larger than this, as found for ultrafine particles produced from welding fume. Many nanomaterials are supplied as powders which are highly agglomerated, but even during the manufacture of the primary nanoparticles they quickly agglomerate with each other and any other particles present in the air.

This means that if a 20 nm primary particle size nanomaterial is being produced or supplied, attempting to monitor only particles below 100 nm is likely to give only a very limited assessment of the actual exposure to that nanomaterial. Therefore, the challenge for any exposure measurement is to measure all the nanomaterial that could be inhaled or at least that which can reach the deep lung (respirable fraction) where it might be more difficult to clear.

5.2 Identification of nanomaterials

Unless released into a clean room, the background of particles already present in the air could be substantial (background particle counts of 10 nm to 1 000 nm sized particles are often as high as several thousand, sometimes tens of thousand, particles per mL or higher). Therefore, there are considerable peak:background challenges in detecting the release of nanomaterials into room air. This means that particle number and particles size distribution information is not specific to the nanomaterials of interest, so that further identification of the types of particles being measured might be necessary to ensure that the source and level of the nanomaterial emission are properly identified. Other common sources of ultrafine particle emission include electric motors, combustion sources, fumes and sprays.

5.3 Activities and scenarios

Exposure to airborne particles of nanomaterials can potentially occur for workers at all phases of the material life cycle. During the development of a new material, the material will probably be produced under tightly controlled conditions, typically in very small quantities. Accidental releases due to spills and accidents are possible. Once the material moves into commercial production, exposures can potentially

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occur during synthesis of the material or in downstream activities such as recovery, packaging, transport, storage and maintenance. In these circumstances, the quantities of materials being handled will typically be much larger.

Depending on the specific properties of the new material, it might be incorporated subsequently into a range of other products or used in other processes as a feed-stock material. Nanomaterials can also be incorporated, for example, into a composite material which could subsequently be re-engineered or reprocessed, e.g. by cutting, sawing or finishing. Again, there is a potential for exposure to nanomaterials if they are released from the matrix. In an end–of-life scenario the material could be disposed of by incineration or some other process such as shredding or grinding. All of these scenarios have the potential to release airborne particles to which workers could be exposed. In conclusion, for a single material, there are multiple exposure scenarios which might or might not occur depending on the details of its manufacture, use and disposal. Throughout these scenarios, the population exposed, the levels of exposure, the duration of exposure and the nature of the material to which people are exposed are all different.

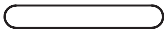
Exposure studies for nanomaterials are being undertaken which reflect these scenarios. A non-exhaustive list of possible exposure scenarios is given in Table 1, together with the probable characteristics of the aerosol release and references to literature in which these scenarios have been reported. These scenarios illustrate the complex nature of the aerosol to which exposure might need to be assessed.

Table 1 **Plausible examples of exposure scenarios and the possible aerosol release**

Example scenarios	Possible aerosol release	Reference
Reactor leak during gas phase NP synthesis	Discrete NP, agglomerate/aggregate NP	[12],[13]
Spray leak during liquid phase NP synthesis	NP within larger droplets of reactor fluid	
	Dry aggregates/agglomerates of NP following evaporation	
Leak during spray drying of NP product	Aggregates/agglomerates of NP	
Bagging and handling of NP product	Aggregates/agglomerates of NP	[14],[15]
Mixing of composite during manufacture	Aggregates/agglomerates of NP	[16]
Finishing (cutting, sawing, polishing) of composite	Aggregates/agglomerates of NP with binder	[17]
Spray application of a product containing suspension of NP	NP within larger droplets of solvent	
	Dry aggregates/agglomerates of NP following evaporation	
Disposal/Incineration of composite containing NP	Discrete NP, agglomerate/aggregate NP, NP with incineration by products	

Maynard and Aitken [18] suggested a classification scheme for these different forms of nanomaterials, which is helpful in developing measurement approaches. This scheme is shown in Figure 4 in modified form.

Figure 4 **Types of nanomaterials**

Class	Particle type	Description
A		**"Spherical" particles** Compositionally homogeneous, discrete NP Single size (monodisperse)
B		**Simple non-spherical particles (HARN)** Compositionally homogeneous, discrete Single size (monodisperse)
D		**Homogeneous agglomerates** Agglomerates/aggregates of compositionally homogeneous monodisperse particles
D'		**Homogeneous agglomerates (HARN)** Agglomerates/aggregates of compositionally homogeneous monodisperse particles
G'		**Heterogeneous agglomerates** Agglomerates/aggregates of diverse particle types or sizes
G		**Heterogeneous agglomerates (including HARN)** Agglomerates of diverse particle types, including HARN

6 Strategy for exposure assessment

6.1 Basic approach

Currently, there is no single consensus view on the most appropriate method for assessing exposure to nanomaterials. Initial approaches, for example that described by Brouwer *et al* [19], use a multi-instrument approach in an attempt to capture all relevant metrics and characteristics. The National Institute for Occupational Safety and Health (NIOSH) has developed a multi-stage strategy (NEAT) involving an initial assessment by a condensation particle counter (CPC) and an optical particle counter (OPC), plus electron microscopy and elemental identification [20].

The basic approach to assessing exposure to nanomaterials builds on these approaches. It can be described in five steps:

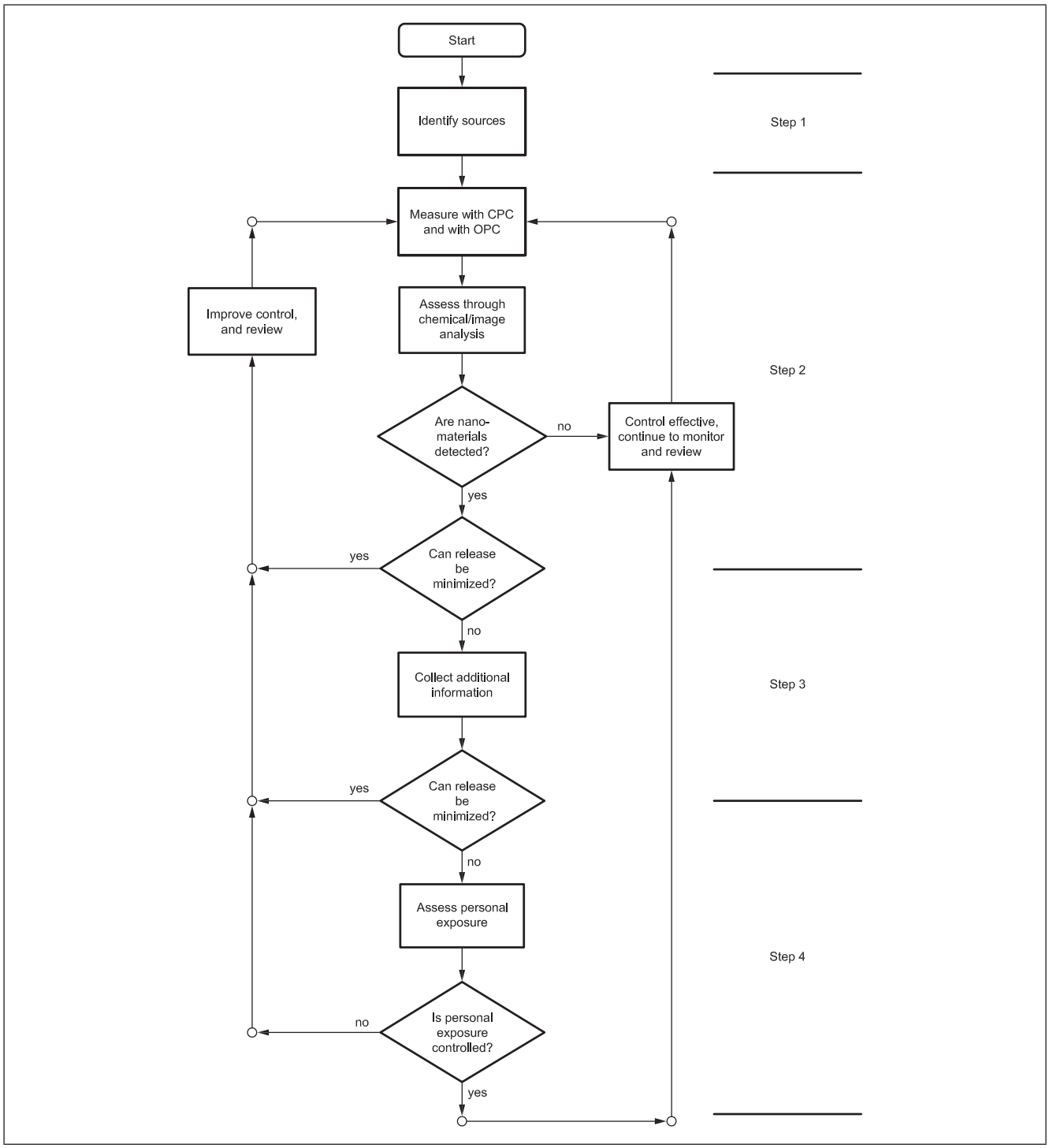
- Step 1: Identify the source of emissions;
- Step 2: Basic assessment, measurements at source;
- Step 3: Detailed assessment;
- Step 4: Personal sampling;
- Step 5: Analysis of data.

A process diagram which represents the relationship between these steps is shown in Figure 5. These steps are explained in detail in **6.4**.

6.2 Purpose

As with all exposure assessment programmes it is necessary to define the purpose of the exercise. There are a number of potential reasons for carrying out a programme to assess exposures, e.g. detection of emissions, assessment of compliance with external or in-house control limits, assessment of the effectiveness of exposure control measures or collection of data for use in an epidemiology or other health impacts study. The purpose of the measurement programme will largely determine the type of approach used.

Figure 5 **Exposure assessment process diagram**



6.3 Selection of instruments

Instruments and approaches are available which can measure mass concentration, number concentration, surface area concentration and size distribution. In all cases, however, there are limitations to the applicability of these instruments and the interpretation of the data which they produce. The main instruments available for use in an exposure assessment for nanomaterials are summarized in Clause **7** and Annex A.

6.4 Assessment approach

By using a combination of instruments, an assessment of worker exposure to nanomaterials can be conducted. The approach described here is based on standard occupational hygiene practice, but has been adapted to provide specific information on the exposures of interest. This approach allows a determination of the presence and identification of nanomaterials, and the characterization of the important aerosol metrics. However, given the uncertainties in the state of the science, a simple yes/no decision tree approach might not always be possible. The effectiveness of controls cannot solely be determined from exposure measurement. Nano-objects might not be detected due to high background fluctuations or process variations, or insufficient sample time or volume. Contextual information is also important in the decision-making process.

The outcomes of each step should be carefully considered before a decision is taken as to whether to progress to the next step.

Step 1: Identify the source of emissions

Identify the possible sources of exposure in the work environment, considering all potential pathways and factors. Identify process and tasks. Depending on the scenario, tasks might include synthesis of nano-objects, recovery and bagging, maintenance, use of products containing nano-objects and machining of surfaces coated with nano-objects. Consider also at this stage numbers of potentially exposed workers and frequency of exposure. Other potential sources of nanomaterials need to be identified at this stage.

Step 2: Basic assessment, measurements at source

Conduct some initial measurements to gain an understanding of where nano-objects are being emitted for the process or task of interest. Measurements should be made as close as possible to the source. A CPC is acceptable for this purpose, due to its portability and rapid assessment potential. This device provides information on particle number concentration. In using such a device, it is critical to monitor ambient or background particle counts after and/or before measuring particles being emitted from the process of interest (see **7.5.2**).

CPC will not generally detect particles greater than 1 000 nm. If it is possible that aggregates or agglomerates of nano-objects larger than this are present, an OPC with a range extending to larger particles should also be used.

If high airborne releases of nanomaterials are detected at this stage, the exposure assessment may be suspended after one or more of the steps to allow re-engineering of the process before restarting the assessment process.

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Further information as to the nature of the release can be obtained by image and chemical analysis of emitted particles. Having identified where particles are being released, information as to their nature can be obtained by collection of particles on to a filter or other suitable substrate, followed by identification by analytical SEM/TEM. (High resolution optical microscopy can be useful for identifying larger agglomerates/aggregates of size between 300 nm and 10 μm.) Particles can be collected onto a filter using a size-selective sampler conforming to the respirable or inhalable fraction. Alternatively, thermal or electrostatic precipitators can be used to deposit particles directly on to collection substrates, such as TEM grids.

Information on the chemical composition can be obtained using techniques such as energy dispersive x-ray (EDX) (analysing objects imaged by SEM/TEM) or inductively coupled plasma optical emission spectrometry (ICP-OES)/inductively coupled plasma mass spectroscopy (ICP-MS) for filter samples. The purpose of this is to identify whether the collected materials have the same chemical composition as the nano-objects used in the process or task.

A formal decision logic has been proposed by Brouwer *et al* [3]. In this, the average concentration during the period of the activity should be more than 5% greater than that during a period of inactivity (near field background), or at some distance from the activity (far field background). Secondly, the characterization of the samples during the activity by analytical electron microscopy ought to indicate the presence of primary particles or agglomerates/aggregates. The EDX elemental analysis is used to confirm that the (elemental) identity of the objects or agglomerates is similar to the nano-objects in the process or task.

There are likely to be particular difficulties in assessing HARN, such as CNT, using direct reading instruments like the CPC. If these are present in the air, they will most likely be in an agglomerated or aggregated form (although the possibility of single CNT cannot be excluded). If HARNs are believed to be present it is important to obtain high resolution images of the aerosol to confirm their presence.

A positive indication of the presence of nanomaterials would indicate a need to improve the level of control. If improved control cannot be achieved, a more detailed assessment might provide additional information to understand the nature of the release and to identify effective control approaches.

Step 3: Detailed assessment

In some cases it might be useful to collect additional information to reinforce the decisions made in Step 2 or if further characterization is necessary. Useful additional information could include size distribution, measurement of surface area concentration, or mass concentration. Instruments should be selected based on what can be discerned about the nature of the emissions, for example, which aerosol classes are present and the parameters of greatest interest. Instrument selection should be based on knowledge of the characteristics of the aerosol present, consideration of the most appropriate metric, and knowledge of the performance and limitations of the available measurement method.

At this stage instruments are likely to be static instruments, rather than personal samplers. The location of these instruments should be considered carefully. Ideally, they should be placed close to the work areas of the workers, but other factors, such as size of

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the instrumentation and power source, need to be considered. Consideration should be given to potential losses in the sampling line between the entry point (which could be in the breathing zone of a worker) and the instrument.

Step 4: Personal sampling

If, after collection of additional detailed information in Step 3, there remains a concern that nanomaterials are being released into the workplace air, it will be necessary to quantify personal exposure.

An appropriate strategy should be developed based on the information collected on the likely sources and nature of the aerosol. This would include who and what to measure, use of personal or static measurements, numbers of measurements to be taken, duration of measurements, and selection of appropriate methods. Methods can be direct or involve the use of proxies, e.g. measurement of CNT by measuring any contaminant present as part of the manufacturing process. Personal sampling using filters or grids suitable for analysis by electron microscopy or chemical identification can be used to examine the relationship between static samples collected close to the site emissions and personal exposures. Again, selection of the instruments and analytical approaches used will depend on the characteristics of the nanomaterials released. Examples include chemical analysis to determine mass or electron microscopy to provide information on shape of particles/agglomorates and chemical information, and an estimate of the size distribution of the particle of interest.

7 Instruments and techniques available for monitoring exposure

7.1 General

Instruments and techniques are available which can measure mass concentration, number concentration, surface area concentration and size distribution. In all cases, however, there are limitations to the applicability of these instruments and the interpretation of the data which they produce. These are summarized in Table 2.

7.2 Measurement of particle number concentration

Measurement of particle number concentration is relatively straightforward with condensation particle counter (CPC) devices. Typically hand-held devices, CPCs operate by condensing vapour onto particles in a sampled air-stream to grow them to a size range that can be detected optically. The detection range is typically 3 nm to 20 nm at the lower end to 1 000 nm at the upper end, depending on the instrument used. However, issues remain in knowing precisely the upper and lower size ranges where particles can be detected. This single measure will be dominated by these limitations, particularly between different types of CPC where the boundaries could differ, but also within the same type depending on the stability and reproducibility of the boundary ranges of these instruments. Measuring particle number concentration in isolation can therefore be misleading.

Optical particle counters (OPCs) measuring particle number concentration can be useful for identifying larger agglomerates/aggregates of size between 300 nm and 10 μm).

Table 2 **Available instruments and techniques for monitoring nanomaterial exposure (from PD ISO/TR 27628:2007)**

Metric	Devices	Remarks
Mass	Size-selective personal sampler	No current devices offer a cut point of 100 nm. Off-line gravimetric or chemical detection is necessary. 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. Size-selected samples may be further analysed off-line.
Number	CPC	CPCs provide real-time number concentration measurements between their particle diameter detection limits. Without a nanoparticle preseparator, they are not specific to the nanometre size range (no suitable preseparators 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 to 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. For instance, the mobility diameter of open agglomerates has been shown to correlate well with projected surface area [21].
	ELPI	Real-time size-selective (aerodynamic diameter) detection of active surface-area concentration. Active surface area does not scale directly with geometric surface area above 100 nm. 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.

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Table 2 **Available instruments and techniques for monitoring nanomaterial exposure (from PD ISO/TR 27628:2007)** *(continued)*

Metric	Devices	Remarks
Surface Area *(continued)*	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 the particle active surface area below 100 nm. Diffusion chargers are only specific to nanoparticles if used with an appropriate inlet preseparator.
	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 the geometric area for some particle shapes.

7.3 Measurement of particle mass concentration

Measuring aerosol mass concentration is standard procedure in the workplace and environment. The simplest approach is to use a filter-based personal sampler comprising some form of inertial particle pre-selector, together with off-line analysis of the sample using gravimetric or chemical techniques. Most of the filters used for occupational aerosol sampling will collect nano-objects. In workplaces these samplers are most often used to measure the inhalable or respirable fraction of an aerosol. Respirable and inhalable samplers are appropriate for the measurement of airborne particles, but are not able to distinguish discrete nano-objects from other, larger particles. Large error in mass measurements can result from the presence of relatively few large particles. The mass concentration of discrete nano-objects could be measured using a size selective personal sampler which incorporates a pre-selector to exclude particles larger than approximately 100 nm in diameter, although there are no commercial devices of this type currently available. The mass concentrations of nano-objects will in most cases be too low for gravimetric assessment.

Optical aerosol monitors (photometers) are widely used to measure aerosol mass concentration. However, while they can be useful in measuring exposure to aggregated or agglomerated nano-objects in the respirable size range, detection efficiency falls off rapidly below approximately 500 nm. They are, therefore, unsuited to measuring the mass concentration of discrete airborne nano-objects.

7.4 Measurement of specific surface area concentration

There are now several devices which provide the possibility to measure specific surface area, based on the principle of diffusion charging [22]. Diffusion chargers operate by measuring the attachment rate of unipolar ions to particles, which relates to the specific surface area of the aerosol. Particles are subsequently captured in an electrometer. By measuring the charge an estimate of the specific surface area can be derived. Wilson *et al* [23] described the use of a variant of this device, an electrical aerosol detector (EAD), to measure the total particle surface area deposited in the lung. Shin *et al* [24] demonstrated that the response function of an EAD can be modified by altering the voltage of its ion trap which selectively removes a portion of the aerosol such that

the output provides a measure of the deposited surface area in the lung. A commercial device for this is now available.

Currently, there is little published practical experience of using these devices to assess exposure in real workplace situations. Nevertheless, surface area is likely to be a metric of considerable importance and interest, particularly for more complex structures and particles.

7.5 Measurement of size distribution

7.5.1 Instruments

Several devices allow examination of the size distribution of any aerosol measured. These instruments are typically larger, more complex and more expensive than those that measure number concentration alone. The most commonly used instrument of this type is the SMPS, of which there are a number of variants. These devices are capable of measuring aerosol size distribution from approximately 3 nm to 800 nm, although not simultaneously over the complete range. The size distribution is expressed in terms of particle mobility diameter. SMPS instruments comprise two parts: a stepped (in which the classifier voltage is stepped between discrete voltage levels) or scanning (in which the voltage is varied continuously) differential mobility analyser (DMA), which sequentially separates sampled aerosol into size intervals according to their differential mobility, and a CPC which then counts the particles in sequence. The DMA operates by charging particles, typically by passing them through an ion cloud formed from a radioactive source such as 85Kr or 241Am. The particles then pass through a well-defined electrostatic field. Electrostatic forces lead to charged particles moving between the electrodes, and particles with a specific electrical mobility are sampled from the exit of the electrodes, and counted. By scanning the voltage between the electrodes, particles with electrical mobilities corresponding to a range of particle diameters are allowed to pass through and are counted sequentially, using a CPC. This allows the aerosol size distribution to be determined.

A disadvantage of the SMPS is that it is relatively slow and requires a scanning approach to measure different size intervals in series (taking several minutes).

A more recent development is the FMPS. This instrument initially charges the aerosol using a unipolar charger, and measures the mobility diameter distribution with a parallel array of electrometer based sensors. Measurements can be made with a time resolution of one second or less, and operation at ambient pressures reduces evaporation of volatile particles. However, the advantages of this approach are offset to a degree by the instrument being larger and more costly than a SMPS, and typically less sensitive at low particle concentrations.

A number of instruments enable aerosol mass concentration to be measured as a function of particle size, down to nanometer diameters. Cascade impactors consist of several (usually up to about 10) impactor stages connected in series with progressively smaller cut-point diameters depending on the air velocity and the distance from the nozzle to the impaction plate. One such impactor, which operates in the nanometer size range, is the nanoMOUDI which has cut-point stages of 10 um, 5.6 um, 3.2 um, 1.8 um, 1 um, 560 nm, 320 nm, 180 nm, 100 nm, 56 nm at 30 lpm inlet flow with final filter and single stage pre-impactor of

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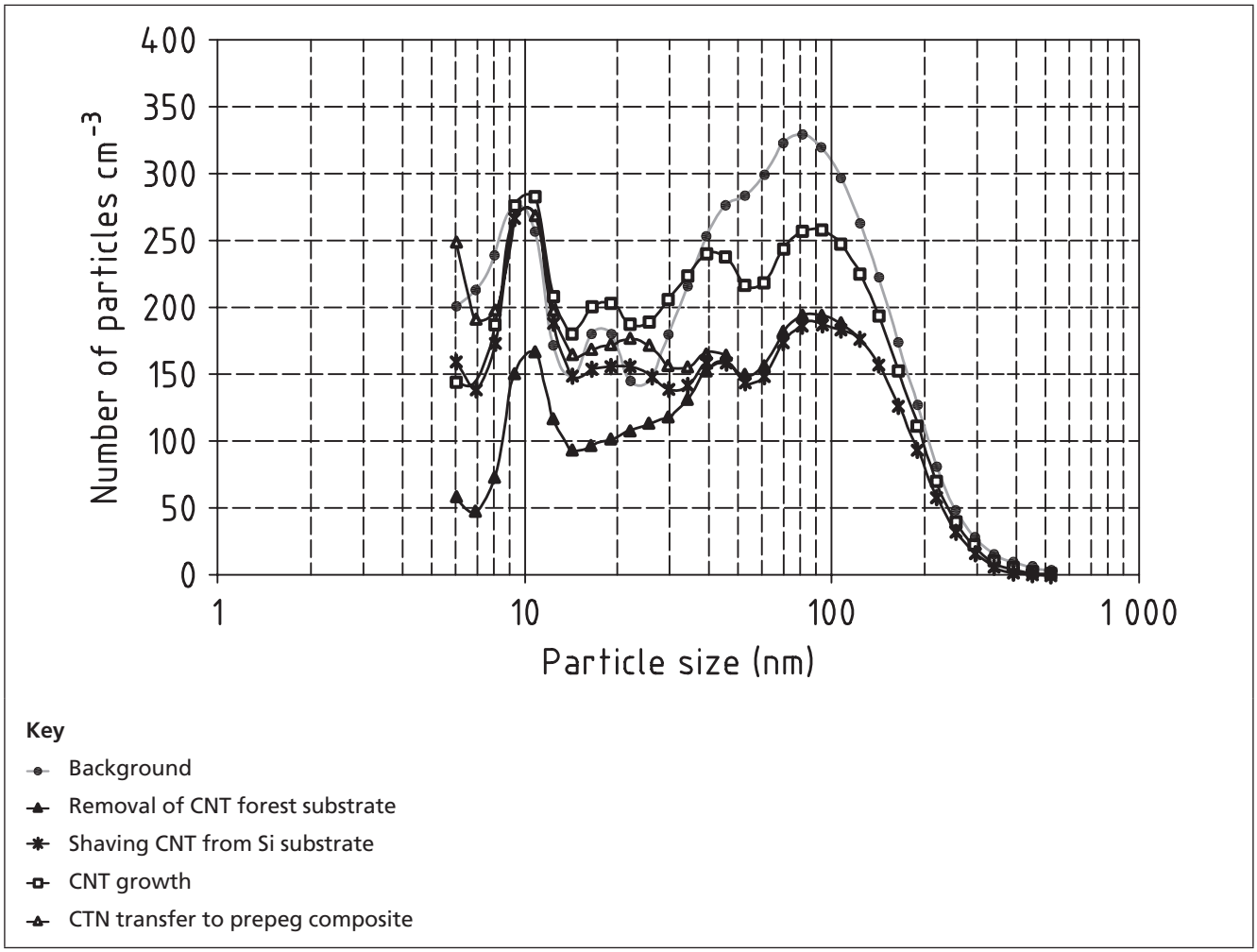
18 um. The electrical low pressure impactor (ELPI, Dekati, Finland) is a static aerosol sampler capable of measuring particle size distribution and concentration in the size range 7 nm to 10 µm. Particles sampled in the ELPI are charged and then passed into a low-pressure cascade impactor with a series of thirteen electrically isolated collection stages. Each stage collects progressively smaller particles, enabling the size distribution of the aerosol to be estimated. The electrical current carried by the charged particles onto each impactor stage is measured in real-time by a sensitive multi-channel electrometer. This device therefore enables direct on-line measurement of the mass of nano-objects (data may be interpreted in terms of mass concentration if particle charge and density are assumed or known). One further advantage of the instrument is that, if desired, collected particles can be removed from the impactor stages at the end of the sampling period for off-line analysis.

7.5.2 Handling size distribution data

Devices which measure size distribution provide a particularly data-rich output, usually producing count data in several size bins. There are several ways in which these data might be used. The simplest approach is to inspect the complete size distribution. This is particularly useful in assessing single events or single changes (e.g. the implementation of a control measure, or the comparison between an aerosol and a background). An example of this is provided in Figure 6 from Bello *et al* [25].

Figure 6 **FMPS size distributions**



This type of analysis, though, is difficult to quantify. One option is to sum the total counts to provide a single number. However, this approach loses the size information and is therefore of limited value. Several authors [15] have grouped this type of data into several broad size ranges, e.g. <10 nm, <100 nm, <1 000 nm, and examined the time series for each. This can be highly effective in examining how different parts of an aerosol distribution change with time.

7.6 Measurement of HARN

The utility of image analysis in assessing exposure to nanomaterials is clear, particularly so in the case of HARN which could be present in multiple forms. It is extremely unlikely that any automated form of real-time instrumentation will be able to usefully discriminate between the different types of materials which could be present in an aerosol. Ultimately, this will rely on high-resolution microscopy techniques. Some progress in image analysis is being made, particularly the project being carried out by NIOSH (http://www.cdc.gov/niosh/) which is attempting to pre-select various forms of aerosol objects that could be present in a complex aerosol before depositing these onto substrates for subsequent automated analysis. However, this has not yet progressed to the point of being a useable method. The emergence of an automated system for HARN is unlikely in the near future.

It follows then that, to obtain any useful information about the morphology of aerosols formed from HARN, analysis should be carried out using high-resolution microscopy techniques.

7.7 Personal sampling

There has been little progress towards developing an effective personal sampler, as first described by Maynard and Aitken [18]. In fact, there are currently no specific personal sampling solutions available for any of the metrics relevant for assessing exposure to nanomaterials. Personal sampling should be carried out using conventional personal samplers for the respirable and thoracic fractions.

7.8 Maximum particle size

All of the studies discussed so far seek to maximize the information available by looking at a wide particle size range. There does seem to be utility in devices, such as the CPC, which provide a total number of particles to introduce some effective range. In practice, many of these devices have a cut-off of approximately 1 000 nm, although this is often only a "nominal" upper limit. There currently seems little value in recommending any lower cut-off than this size. It might well be that clusters of nano-objects, etc., which could run to the size of several hundreds of nanometres, are still of potential interest from a risk perspective. To harmonize sampling with established conventions and to ensure all particles capable of penetrating to the deep lung will be sampled, use of the respirable convention to define the maximum particle size is recommended. Where the instrument already has a lower cut-off, a limit of 1 000 nm is appropriate.

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7.9 Combination of instrument data

When multiple measures are being made, or when size distribution information is being collected, there is greater utility in extending the range of particle sizes collected as this will provide a more complete picture of the nature of the aerosol present. There is therefore value in extending the SMPS range by including parallel measurements with an instrument which can measure size distribution at a larger size range. One such instrument is the aerodynamic particle sizer (APS) which provides size distribution information from 500 nm to 20 000 nm. There are data handling issues to be considered in trying to combine the output from these two devices.

7.10 Discrimination from background aerosol contribution

Typical urban air contains anywhere between 10 000 particles·cc^{-1} and 40 000 particles·cc^{-1} which come from a variety of sources, including industrial pollution, traffic and domestic emissions. Levels in indoor air, particularly in air-conditioned buildings, can be much lower, but equivalent particle numbers can be generated by activities such as heating, cooking and vacuuming. These number concentrations are dominated by particles smaller the 1 000 nm and much of the distribution is typically in the range 10 nm to 300 nm. The presence of this ambient particulate creates problems when attempting to measure emissions of engineered nano-objects in this size range.

Devices which simply count particles, such as condensation particle counters (e.g. CPC), are unable to discriminate between ambient environmental particles and emitted engineered particles.

It is important to identify and take account of these contributing sources.

Two approaches can be used to try to discriminate background aerosol contribution from that produced by the process under investigation. The first is a time series approach in which the parameter of interest (e.g. particle number concentration) is tracked in real time and the data obtained compared with a log of activities occurring in the workplace to identify other contributing activities and to quantify the contribution made.

A second approach is to take parallel samples in the area where it is expected that there is only background aerosol present, i.e. there is no expected contribution from the source. In adopting this type of approach, care needs to be taken that there is indeed no contribution from the source or from any other sources in the "background sample" area.

Although particularly suited to real-time instrumentation, these types of approach could also be applied to analysis of off-line samples.

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Annex A (informative)

Selection of instruments

It is likely that reliance will continue to be placed on multiple methods of analysis for some time. It is, therefore, critically important that the limitations of these are understood. Some of the main issues and limitations are summarized in Table A.2 to Table A.5, in which measurement options are mapped out for six different categories of nanomaterials described in Clause **5** (a guide to the table applicable to each particle type is given in Table A.1). Each table provides information for a specific category of nanomaterials relating to each metric of interest, the appropriate instrument, what is measured and the applicable caveats and limitation.

Table A.1 **Tables applicable to particle types**

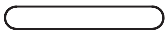
Class	Particle type	Description	Table
A		**"Spherical" particles** Compositionally homogeneous, discrete NP Single size (monodisperse)	A.2
B		**Simple non-spherical particles (HARN)** Compositionally homogeneous, discrete Single size (monodisperse)	A.3
D		**Homogeneous agglomerates** Agglomerates/aggregates of compositionally homogeneous monodisperse particles	A.4
D′		**Homogeneous agglomerates (HARN)** Agglomerates/aggregates of compositionally homogeneous monodisperse particles	A.5
G′		**Heterogeneous agglomerates** Agglomerates/aggregates of diverse particle types or sizes	A.3
G		**Heterogeneous agglomerates (including HARN)** Agglomerates of diverse particle types, including HARN	A.5

Table A.2 **Method assessment for discrete, approximately spherical nanoparticles – Category A**

Metric		Options	What it would measure	Caveats and limitations
Mass concentration	A	Filter holder with inhalable inlet	Period averaged inhalable mass concentration	Methods A, B and C will produce the same result
	B	Filter holder with respirable inlet	Period averaged respirable mass concentration	Methods A, B and C will produce the same result
	C	Filter holder with 1000 nm inlet	Period averaged mass concentration <1 000 nm	Methods A, B and C will produce the same result
	D	TEOM with PM10 inlet	Real time mass concentration <10 000 nm	Methods D, E and F will produce the same result
	E	TEOM with PM2.5 inlet	Real time mass concentration <2 500 nm	Methods D, E and F will produce the same result
	F	TEOM with PM1.0 inlet	Real time mass concentration <1 000 nm	Methods D, E and F will produce the same result
	G	Light scattering devices (e.g. DUSTTRAK™)	No useful information	Insensitive to particles less than 100 nm
	H	Optical microscopy	No useful information	Insensitive to particles less than 100 nm
	I	SEM/TEM	Number concentration and size which can be converted to mass by calculation	
Mass size distribution	K	ELPI	Mass concentration in series of stages	Limited size steps less than 100 nm (3), LOD issues for low mass
	L	Low pressure impactor	Mass concentration in series of stages	Limited size steps less than 100 nm, LOD issues for low mass
	M	WRAS	Mass concentration in series of stages	Extended size range by using diffusion charger and impactor in line
Number concentration	N	OPC	No useful information	Will not detect at this size range due to low detection limit of 100 nm
	O	CPC with respirable inlet	Real time respirable number concentration	Will detect all particles down to lower detection limit
	P	CPC with 1 000 nm inlet	Real time number concentration <1 000 nm	Will detect all particles down to lower detection limit
	Q	SMPS	Quasi real time number size distribution 10 nm – 800 nm, can be summed to one or more bins	All particles greater than 10 nm detected, data can be integrated into 1 or several size groupings
	R	FMPS	Real time number size distribution 10 nm – 500 nm, can be summed to one or more bins	All particles greater than 10 nm detected, data can be integrated into 1 or several size groupings
	S	APS	No useful information	Will not detect particles in the nanoscale due to detection limit of 500 nm
	T	Optical microscopy	No useful information	Insensitive to particles less than 100 nm
	U	SEM/TEM	Number concentration	
	V			
Number size distribution	W	ELPI	Number concentration in series of stages	Limited size steps less than 100 nm
	X	SMPS	Quasi real time number size distribution 10 nm – 800 nm	
	Y	FMPS	Real time number size distribution 10 nm – 500 nm	
	Z	APS	No useful information	
Surface area concentration	A1	Diffusion charger	Total surface area concentration	Subject to maximum and minimum sizes and some material dependency

Table A.3 **Method assessment for discrete HARN – Category B**

Metric		Options	What it would measure	Caveats and limitations
Mass concentration	A	Filter holder with inhalable inlet	Period averaged inhalable mass concentration	Methods A, B and C will produce the same result
	B	Filter holder with respirable inlet	Period averaged respirable mass concentration	Methods A, B and C will produce the same result
	C	Filter holder with 1000 nm inlet	Period averaged mass concentration <1 000 nm	Methods A, B and C will produce the same result
	D	TEOM with PM10 inlet	Real time mass concentration <10 000 nm	
	E	TEOM with PM2.5 inlet	Real time mass concentration <2500 nm	
	F	TEOM with PM1.0 inlet	Real time mass concentration <1000 nm	
	G	Light scattering devices (e.g. DUSTTRAK™)	No useful information	Will not detect at this size range due to low detection limit of 100 nm
	H	Optical microscopy	No useful information	Insensitive to HARN less than 100 nm diameter
	I	SEM/TEM	Number concentration which can be converted to mass by calculation	Counting rules required to be developed
Mass size distribution	K	ELPI	Mass concentration in series of stages	Size selection not evaluated for HARN, limited size steps less than 100 nm (3), LOD issues for low mass
	L	Low pressure impactor	Mass concentration in series of stages	Size selection not evaluated for HARN, limited size steps less than 100 nm, LOD issues for low mass
	M	WRAS	Mass concentration in series of stages	Not evaluated for HARN, capture by interception might be problematic
Number concentration	N	OPC	No useful information	Will not detect at this size range due to low detection limit of 100 nm
	O	CPC with respirable inlet	Real time respirable number concentration	Not evaluated for HARN, will detect all particles down to lower detection limit
	P	CPC with 1000 nm inlet	Real time number concentration <1 000 nm	Not evaluated for HARN, will detect all particles down to lower detection limit
	Q	SMPS	Quasi real time number size distribution 10 nm – 800 nm, can be summed to one or more bins	Not evaluated for HARN, size information not dependable
	R	FMPS	Real time number size distribution 10 nm – 500 nm, can be summed to one or more bins	Not evaluated for HARN, size information not dependable
	S	APS	No useful information	Will not detect at this size range due to low detection limit of 500 nm
	T	Optical microscopy	Number concentration	Will not detect HARN with diameter less than 100 nm
	U	SEM/TEM	Number concentration	Potentially useful, counting rules required to be evaluated/developed
Number size distribution	W	ELPI	Number concentration in series of stages	Not evaluated for HARN, size information not dependable
	X	SMPS	Quasi real time number size distribution 10 nm – 800 nm	Not evaluated for HARN, size information not dependable
	Y	FMPS	Real time number size distribution 10 nm – 500 nm	Not evaluated for HARN, size information not dependable
	Z	APS	No useful information	
Surface area concentration	A1	Diffusion charger	Total surface area concentration	Not evaluated for HARN, subject to maximum and minimum sizes and some material dependency

Table A.4 **Method assessment for agglomerated nano-particle – Category D – and heterogeneous agglomerates containing nano-objects – Category G'**

Metric		Options	What it would measure	Caveats and limitations
Mass concentration	A	Filter holder with inhalable inlet	Period averaged inhalable mass concentration	
	B	Filter holder with respirable inlet	Period averaged respirable mass concentration	Larger inhalable agglomerates excluded
	C	Filter holder with 1000 nm inlet	Period averaged mass concentration <1000 nm	Some respirable agglomerates excluded
	D	TEOM with PM10 inlet	Real time mass concentration <10000 nm	Larger inhalable agglomerates excluded
	E	TEOM with PM2.5 inlet	Real time mass concentration <2500 nm	Some respirable agglomerates excluded
	F	TEOM with PM1.0 inlet	Real time mass concentration <1000 nm	Some respirable agglomerates excluded
	G	Light scattering devices (e.g. DUSTTRAK™)	Mass concentration for various size ranges	Will only detect larger agglomerates; smaller agglomerates and primary particles excluded, material specific response
	H	Optical microscopy	Number concentration and size which can be converted to mass by calculation	Will only detect larger agglomerates (>200 nm); smaller agglomerates and primary particles excluded, mass underestimated
	I	SEM/TEM	Number concentration and size which can be converted to mass by calculation	
Mass size distribution	K	ELPI	Mass concentration in series of stages	Limited size steps less than 100 nm (3), LOD issues for low mass
	L	Low pressure impactor	Mass concentration in series of stages	Limited size steps less than 100 nm, LOD issues for low mass
	M	WRAS	Mass concentration in series of stages	Extended size range by using diffusion charger and impactor in line
Number concentration	N	OPC	Will detect only larger agglomerates	Will only detect larger agglomerates; smaller agglomerates and primary particles excluded, material specific response
	O	CPC with respirable inlet	Real time respirable number concentration	Will detect particles down to lower detection limit, larger inhalable agglomerates excluded
	P	CPC with 1 000 nm inlet	Real time number concentration <1000 nm	Will detect particles down to lower detection limit, larger respirable agglomerates excluded
	Q	SMPS	Quasi real time number size distribution 10 nm – 800 nm, can be summed to one or more bins	All particles greater than 10 nm detected, data can be integrated into 1 or several size groupings, larger agglomerates (>800 nm) excluded
	R	FMPS	Real time number size distribution 10 nm – 500 nm, can be summed to one or more bins	All particles greater than 10 nm detected, data can be integrated into 1 or several size groupings, larger agglomerates (>500 nm) excluded
	S	APS	Real time number concentration of agglomerates >500 nm	Provides information on large agglomerates
	T	Optical microscopy	Number concentration	Will only detect larger agglomerates (>200 nm), smaller agglomerates and primary particles excluded
	U	SEM/TEM	Number concentration	
Number size distribution	W	ELPI	Number concentration in series of stages	Limited size steps less than 100 nm
	X	SMPS	Quasi real time number size distribution 10 nm – 800 nm	
	Y	FMPS	Real time number size distribution 10 nm – 500 nm	
	Z	APS	Size distribution of large aggregates/agglomerates >500 nm	
Surface area concentration	A1	Diffusion charger	Total surface area concentration	Subject to maximum and minimum sizes and some material dependency

Table A.5 **Method assessment for agglomerated HARN – Category D – and heterogeneous containing HARN – Category G**

Metric		Options	What it would measure	Caveats and limitations
Mass concentration	A	Filter holder with inhalable inlet	Period averaged inhalable mass concentration	
	B	Filter holder with respirable inlet	Period averaged respirable mass concentration	Larger inhalable agglomerates excluded
	C	Filter holder with 1000 nm inlet	Period averaged mass concentration <1 000 nm	Some respirable agglomerates excluded
	D	TEOM with PM10 inlet	Real time mass concentration <10 000 nm	Larger inhalable agglomerates excluded
	E	TEOM with PM2.5 inlet	Real time mass concentration <2 500 nm	Some respirable agglomerates excluded
	F	TEOM with PM1.0 inlet	Real time mass concentration <1 000 nm	Some respirable agglomerates excluded
	G	Light scattering devices (e.g. DUSTTRAK™)	No useful information	Not evaluated for HARN; will only detect larger agglomerates (>200 nm); smaller agglomerates and primary particles excluded
	H	Optical microscopy	Number concentration which can be converted to mass by calculation	Will only detect larger agglomerates (>200 nm); smaller agglomerates and primary particles and HARN excluded
	I	SEM/TEM	Number concentration which can be converted to mass by calculation	Counting rules required, clumps not counted, mass underestimated
Mass size distribution	K	ELPI	Mass concentration in series of stages	Not evaluated for HARN limited size steps less than 100 nm (3), LOD issues for low mass
	L	Low pressure impactor	Mass concentration in series of stages	Not evaluated for HARN; limited size steps less than 100 nm, LOD issues for low mass
	M	WRAS	Extended size range by addition of diffusion charger	Not evaluated for HARN, capture by interception might be problematic
Number concentration	N	OPC	No useful information	Will not detect at this size range due to low detection limit of 100 nm
	O	CPC with respirable inlet	Real time respirable number concentration	Not evaluated for HARN, will detect all particles down to lower detection limit
	P	CPC with 1 000 nm inlet	Real time number concentration <1 000 nm	Not evaluated for HARN, will detect all particles down to lower detection limit
	Q	SMPS	Quasi real time number size distribution 10 nm – 800 nm, can be summed to one or more bins	Not evaluated for HARN, size information not dependable
	R	FMPS	Real time number size distribution 10 nm – 500 nm, can be summed to one or more bins	Not evaluated for HARN, size information not dependable
	S	APS	No useful information	Will not detect at this size range due to low detection limit of 500 nm
	T	Optical microscopy	Number concentration	Insensitive to particles less than 100 nm diameter
	U	SEM/TEM	Number concentration	Counting rules required, clumps not counted, numbers of "fibres" correct
Number size distribution	W	ELPI	Number concentration in series of stages	Not evaluated for HARN, size information not dependable
	X	SMPS	Quasi real time number size distribution 10 nm – 800 nm	Not evaluated for HARN, size information not dependable
	Y	FMPS	Real time number size distribution 10 nm – 500 nm	Not evaluated for HARN, size information not dependable
	Z	APS	Size distribution of large aggregates/agglomerates >500 nm	Not evaluated for HARN, size information not dependable
Surface area concentration	A1	Diffusion charger	Total surface area concentration	Not evaluated for HARN, subject to maximum and minimum sizes and some material dependency

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Further reading

PD ISO/TR 12885, *Nanotechnologies – Health and safety practices in occupational settings relevant to nanotechnologies*

ISO/TS 27687:2008, *Nanotechnologies – Terminology and definitions for nano-objects – Nanoparticle, nanofibre and nanoplate*

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Useful websites

National Institute for Occupational Safety and Health (http://www.cdc.gov/niosh/).

SAFENANO (www.safenano.org).

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