

Working Safely with Nanomaterials in Research & Development

Developed by

**The UK NanoSafety Partnership Group
(UKNSPG)**

This guidance has been produced by The UK NanoSafety Partnership Group (UKNSPG) with contributions from the HSE. It provides help to research establishments and academia on how to comply with their occupational health and safety legal obligations; it also provides additional information to help make improvements to health and safety systems when working with nanomaterials.

It should be noted that the guidance may go further than the minimum you need to do to comply with the law.

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Foreword by Judith Hackitt CBE

As an engineer myself, I find the new technological developments taking place around us today very exciting.

When we consider the challenges which face our own and future generations on this planet there is no doubt at all that we need the very best of scientific and technological innovation to provide solutions in healthcare, medicine, energy, climate change, transport and just about every other aspect of the unsustainable way we live our lives today. Nanomaterials have potential application in all of these fields.

As a regulator, HSE sees its role as enabling business to develop and grow while influencing health and safety issues in the development and introduction of new technologies. We all recognise that there are many benefits offered by nanomaterials and that understanding and managing the risks they may pose is vital to enabling them to be developed to their full potential.

Partnership working brings together key players in workplace health and safety who are "part of the solution". The UK NanoSafety Partnership Group brings together key experts in the field of nanotechnology and helps to establish links with others who have interests in this fascinating area. I hope to see the Partnership Group continue in the future and expand to include industry representation.

Judith Hackitt CBE
Chair of the Health and Safety Executive

Endorsement

'This guidance has been produced by The UK NanoSafety Partnership Group with contributions from the HSE. It provides help to research establishments and academia on how to comply with their occupational health and safety legal obligations; it also provides additional information to help make improvements to health and safety systems when working with nanomaterials. It should be noted that the guidance may go further than the minimum you need to do to comply with the law.

HSE welcomes the launch of this guidance and will continue to work with partners to ensure that the health and safety risks to employees in the nanotechnologies industry are properly controlled.'

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Scope of Guidance

1 This Guidance Note draws attention to the possible health hazards which could result from exposure to particulate nanomaterials. It gives advice on the precautions that may be needed to prevent or adequately control exposure as required by the [Control of Substances Hazardous to Health Regulations \(COSHH\) 2002](#) (as amended).

2 The aim of this document is to give guidance on factors relating to establishing a safe workplace and good safety practice when working with particulate nanomaterials. The document is applicable to a wide range of nanomaterials, including particles, fibres, powders, tubes and wires as well as aggregates and agglomerates..

3 This guidance is aimed at employers, managers, health and safety advisors, and users of particulate nanomaterials in research and development. It should be read in conjunction with the Approved Code of Practice on COSHH, together with the other literature referred to below and in the Appendices.

4 The document has been produced taking account of the safety information currently available and is presented in the format of guidance and recommendations to support implementation of suitable protocols and control measures by employers and employee by advocating a precautionary strategy to minimise potential exposure. It is intended that the document will be reviewed and updated on a periodic basis to keep abreast of the evolving nature of the content.

5 This document is applicable to a broad set of nanomaterials that include nano-objects such as nanoparticles, nanopowders, nanofibres, nanotubes, nanowires, as well as aggregates and agglomerates of these materials.

6 The term 'particulate nanomaterials' used in this document, applies to these entities, either in their original form or incorporated into materials or preparations from which they could be released.

Terms and Definitions

7 The terms and definitions used in this document are based on internationally accepted definitions wherever possible, specifically those defined by the European Commission (EC) and the International Standards Organisation (ISO). For the purposes of this document, the following terms and definitions apply:

Nanomaterial: as defined by the European Commission (EC, 2011): a natural, incidental or manufactured material containing particles (nanomaterials), in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm - 100 nm. In specific cases and where warranted by concerns for the environment, health, safety or competitiveness, the number size distribution threshold of 50% may be replaced by a threshold between 1 and 50%." By derogation, fullerenes, graphene flakes and single wall carbon nanotubes with one or more external dimensions below 1 nm should be considered as nanomaterials.

Within this definition of nanomaterials, the terms "particle", "agglomerate" and "aggregate" are defined as follows:

"Particle" means a minute piece of matter with defined physical boundaries;

"Agglomerate" means a collection of weakly bound particles or aggregates where the resulting external surface area is similar to the sum of the surface areas of the individual components;

"Aggregate" means a particle comprising strongly bound or fused particles.

Nanofibre: nano-object with two similar external dimensions in the nanoscale and the third dimension being significantly larger [ISO/TS 27687, def. 4.3].

Nano-object: material with one, two or three external dimensions in the nanoscale [ISO/TS 27687, def.2.2].

Nanoparticle: nano-object with all three dimensions in the nanoscale [ISO/TS 27687, def. 4.1].

Nanoplate: nano-object with one external dimension in the nanoscale and the two other external dimensions significantly larger [ISO/TS 27687, def. 4.2].

Nanoscale: size range from approximately 1 nm to 100 nm [ISO/TS 27687, def. 2.1].

Nanotube: hollow nanofibre [ISO/TS 27687, def. 4.4].

Particulate nanomaterial(s): nanomaterials that consist of nano-objects such as nanoparticles, nanopowders, nanofibres, nanotubes, nanowires, as well as aggregates and agglomerates of these materials either in their original form or incorporated in materials or preparations, from which they could be released.

Introduction

8 It is widely accepted that there is a crucial need for further information and knowledge concerning the implications of manufactured particulate nanomaterials on human health and the environment. Concerns regarding potential risks to health that may arise during the manufacture, manipulation, use and disposal of these materials have been voiced over the past few years. Notably, the seminal report from the Royal Society and Royal Academy of Engineering published in 2004 entitled "Nanoscience and nanotechnologies: opportunities and uncertainties" (RS/RAEng 2004) described emerging concerns regarding the potential risks to health associated with nanotechnology and exposure to nanomaterials. Other reports, including those from the Royal Commission on Environmental Pollution (RCEP, 2008), the UK's Health & Safety Executive (see reports available at www.hse.gov.uk/nanotechnology/research.htm) and the UK's Department for Environment, Food & Rural Affairs (see reports available at www.defra.gov.uk/environment/quality/chemicals/) have further depicted the concerns and have gone some way to helping to address them. However, the increasing volumes of particulate nanomaterials that are being produced and introduced into commerce have resulted in an urgent need to address exposure and risk assessment data gaps.

9 This document has been developed in collaboration between the UK Nanosafety Partnership Group and the Health and Safety Executive. It is recognised that the field of nanotechnology is rapidly expanding and transcends the traditional academic discipline boundaries and incorporates a wide range of products, production processes and uses. The document is primarily concerned with the use, storage and disposal of particulate nanomaterials. It does not deal with incidental release of nanomaterials such as those from diesel exhaust and welding fumes.

Legal Duty

10 The occupational use of nanomaterials is regulated under the [Control of Substances Hazardous to Health \(COSHH\) Regulations 2002](#) (as amended).

11 COSHH requires employers to protect workers from exposure to harmful substances in the workplace. Embodying the principles of proportionality and risk assessment, COSHH enables employers to make a valid decision about the measures necessary to prevent or adequately control the exposure of their employees.

12 The chemical and physical properties of some particulate nanomaterials means that they can give rise to a risk of fire and explosion, depending on how they are handled or used. If this is the case, the principle legislation applying to the control of substances that can cause fires and explosions in the workplace is the [Dangerous Substances and Explosive Atmospheres Regulations 2002](#) (DSEAR).

13 DSEAR requires that risks from dangerous substances are assessed and eliminated or reduced so far as is reasonably practicable. The principle of risk assessment applies under these regulations.

14 The Registration, Evaluation, Authorisation & CHemicals ([REACH](#)) regulation is the key piece of EU-wide legislation, which regulates chemicals substances, including nanomaterials.

Exposure Risk and Hazardous Properties of Nanomaterials

15 Exposure to some particulate nanomaterials can occur by ingestion, skin penetration or inhalation, with the resultant adverse effects depending upon the size, dose and toxicity of the nanoparticle. Toxicity investigations indicate that the effects appear to be related to the total surface area of the particles. The exposure potential will be directly related to the structure and form of the nanomaterial. The exposure risk to particles encapsulated in a matrix or strongly adhered to a substrate will be lower than that from 'free' aerosolised, particulate nanomaterials.

16 Some particulate nanomaterials may have inherent hazardous properties and may be classified as carcinogens or mutagens. They may also have other hazardous properties such as toxic, harmful etc, as classified in the Chemicals (Hazard Information and Packaging for Supply) Regulations 2002. It is generally agreed that the current knowledge regarding the toxicity of particulate nanomaterials is incomplete and current safety data sheets may not adequately contain all the required safety information. Hence at present it is essential that a precautionary approach be used when uncertainties are encountered during exposure risk assessment.

17 Fire and explosions from dust clouds of organic, inorganic and metallic substances are well known. The potentially higher surface area and reactivity of particulate nanomaterial powders means that this safety hazard should be seriously considered and addressed in risk assessments.

Risk Management Principles

18 It is important to emphasise that existing legislation in the form of the Control of Substances Hazardous to Health (COSHH) regulations will always apply to workplace activity involving particulate nanomaterials. The guidance and recommendations given in this document closely mirror the eight principles of good practice associated with the COSHH risk assessment process.

19 Nanomaterials are not necessarily intrinsically hazardous *per se* but there is a need to take specific considerations into account during their risk assessment. Therefore one purpose of the above

definition is to provide clear and unambiguous criteria to identify materials for which such considerations apply. The process of risk assessment is the most suitable and systematic means to determine which hazard and exposure controls (i.e. risk management measures) are required.

20 In general, the potential risks to health from particulate nanomaterials can be reduced by safe handling and control of exposure. Whilst no single piece of guidance can provide a definitive, step-by-step approach to safe handling of all nanomaterials in all circumstances, there are a number of general and specific best practice guides that can be used in most applications.

21 The general approach for safe handling and control of particulate nanomaterials is similar to that for other types of chemical substances and seeks to:

- Identify the hazards and assess the risks.
- Decide what precautions are needed.
- Prevent or adequately control exposure.
- Ensure that control measures are used and maintained.
- Monitor the exposure.
- Carry out appropriate health surveillance.
- Prepare plans and procedures to deal with accidents, incidents and emergencies; and
- Ensure employees are properly informed, trained and supervised.

Nanomaterials' Characterisation

Background and challenges

22 Characterisation of nanoparticles plays an essential role in a variety of overlapping contexts ranging from fundamental and applied research, through process and product quality control and commercialisation to health and environmental protection. Fibre-like particles present distinct challenges when characterised using many of today's routine measurement techniques that focus on spherical particles. Moreover, not all particles with the same 'apparent' composition have the same potential to cause harm. As with other chemical substances, appreciation of the relationship between the wide range of physico-chemical characteristics of nanomaterials is important in understanding their toxicology. The implementation of reliable findings from experimental studies into regulatory frameworks with the objective of protecting human and environmental health is also subject to the limitations of inadequately characterised materials and the complexity of mixtures of particles in 'real world' exposures.

23 Nanomaterials may exhibit properties and behaviour that are very different from the bulk-scale materials of the same chemical identity. Knowledge of their size, shape and surface-related properties can be used to account for many of the observed differences. It is widely acknowledged that adequate characterisation of a nanomaterial is therefore necessary to accompany any toxicity study, particularly in cases where particulate nanomaterials (e.g. carbon nanotubes) can be produced by different processes yielding notionally the same material, but which exhibit quite different properties.

24 It is important to recognise that no individual technique can provide an entirely holistic and meaningful characterisation of the sample. Multiple techniques are required to formulate as complete an understanding of the nanomaterial's properties as necessary. Different techniques will suit different sample forms (e.g. aerosol, suspension etc.) and the optimum set of required techniques should be selected based on the specific nanomaterial type, form under investigation and purposes of the study.

25 A further important challenge is how representative the sample is of the material, which may be influenced by the surrounding environment and may change as a function of time.

Selection of properties and techniques for characterisation

26 It is important to recognise that complete characterisation of test materials is time consuming, expensive, complex and may never be fully achievable. The degree of characterisation required depends on the needs or objectives of the study, which can include informing a hazard exposure assessment and overall risk posed by a material. Researchers in the field of nanosafety generally agree however that information on a number of fundamental properties needs to be gathered. These currently include, but are not necessarily limited to composition, size and shape, state of dispersion, surface area and surface chemistry. Any regulatory requirements for characterisation also need to be met.

27 A range of techniques have been adapted or developed for the characterisation of particulate nanomaterials, including microscopic, spectroscopic, spectrometric and chromatographic methods. It is beyond the scope of this document to provide guidance on all properties and techniques. Several reviews and publications are available that can provide appropriate details, as highlighted in the Further Reading. The selection of an appropriate technique depends on the type of material, the required characterisation and the resolution/quality of the data needed.

28 Taking the example of hazard assessment, there is consensus that thorough and accurate particle characterisation are an essential part of assessing the potential toxicity of particulate nanomaterials in biological systems. Information is required on the response to the material against a range of potentially relevant dose metrics, including mass, surface area and number concentration. Appropriate characterisation of test materials is important to ensure that the results are reproducible (within and between laboratories), and also to provide the basis for understanding the properties of particulate nanomaterials that determine their biological effects. Some of the key parameters influencing the biological activity of particulate nanomaterials remain to be fully understood at this point in time. Any study however conducted with material that has not been characterised with respect to a property later found to be critical for toxicity will ultimately be of little value.

29 A rationale, exemplified for hazard assessment above, should be developed and documented that meets the characterisation requirements. It is recommended that best practices advocated in published standards and guidance for nanoparticle characterisation should be adopted.

Toxicology

30 As a crucial and integral part of the risk assessment framework, the understanding of the hazard potential of a substance is important and this is established on the basis of a toxicological assessment. The quantity and quality of toxicological data available dictates the robustness and how informed a hazard assessment can be and this can vary markedly from well-established substances for which a great deal of information exists (e.g. NaCl) to substances that are early in development (e.g. graphene platelets) for which there is little data.

31 The way in which different information levels can affect the type of assessment that can be performed is shown in Figure 1 and the development and adoption of an Occupational Exposure Limit (OEL) from a human safety point of view is the most robust outcome, but this requires a correspondingly high level of data (e.g. well-designed *in vivo* inhalation studies of a sufficient exposure period performed to internationally recognised guidelines). However for many substances (not just nanoparticles), such information is not available and instead lower level toxicological assessments must be used with a corresponding increase in uncertainty and margin for error dependent on the data available.

32 Considering the scheme in Figure 1 in relation to nanomaterials, the level of available toxicological data for most nanomaterials is within the *Minimal* to *Suggestive* range with very few nanomaterials possessing what could be considered *Adequate* information (e.g. TiO₂). Therefore, for a large number of nanomaterials, a hazard/control banding approach is considered the most practical solution in the absence of data for an OEL. It must however be recognised that hazard/control banding approaches for nanomaterials are still very much in the development stage and have not yet been validated.

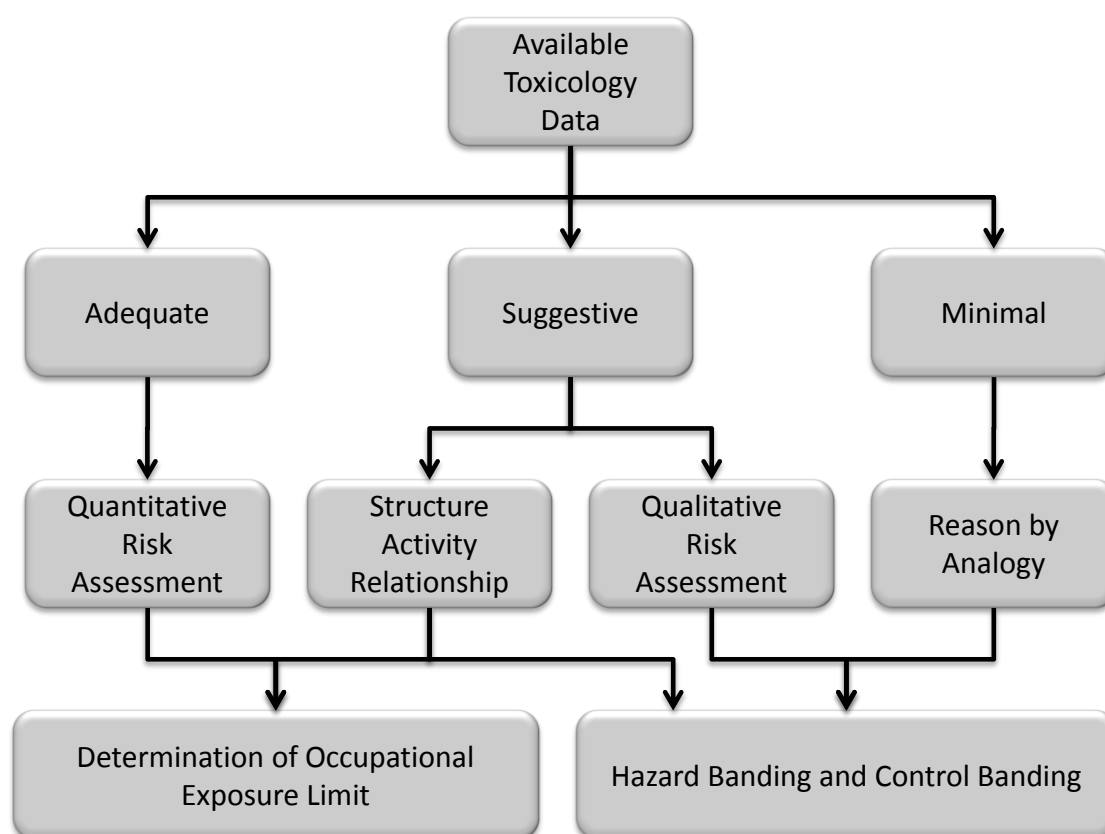


Figure 1: Illustrative example of the level of toxicological data required determining an OEL or using lower level banding approaches (re-drawn from Schulte et al, 2011).

33 When considering the hazard potential of particulate nanomaterials, it is important to understand that the word “nanoparticles” embraces an enormous variety of different materials in different compositions, shapes and sizes (with one or more aspect in the nanometre range). There is therefore no single measure of toxic potency that can be attributed to *all* nanoparticles since there can be considerable variability in toxicity based upon physico-chemical characteristics; specifically, not all nanoparticles are toxic nor equally hazardous. Furthermore, it is important to note that the definition of

the size cut-off for nanoparticles has no basis in toxicology, meaning that there is no step-change in toxicity when a particle becomes below 100 nm in any dimension.

34 When searching for hazard information, it is absolutely necessary to define the nanoparticles that are under consideration in as much detail as possible (see Nanomaterials' characterisation section). For example, "zinc oxide nanoparticles" or "carbon nanotubes" are very broad descriptions, and it would be better to give details such as "20 nm uncoated ZnO nanoparticles" or "multi-walled carbon nanotubes, in fibre form, with length range 620 nm – 52 µm, and 12% iron" as this enables a greater depth of consideration when attempting to describe the potential potency or toxic behaviour.

Hazard Information

35 There is now an evidence base of toxicology of various nanoparticles showing considerable differences in hazard between different nanoparticle types. However, the literature is dominated by studies that employ non-validated *in vitro* tests, which form an unsuitable basis for risk assessment in part because the relationship between *in vitro* toxicological data and *in vivo* effects is unclear. Currently, there are very few inhalation studies on which to base the development of OELs for nanoparticles and those that do exist are limited to a small number of nanoparticles with limited relevance to other forms of nanomaterials.

36 This means that for the majority of nanoparticles there is unlikely to be the in-depth quantitative toxicological data required for the determination of an OEL. Therefore, when such a limit is presented within an MSDS, one should question if it is specifically for the nanoparticle in question, or if it relates to the bulk compound or an analogous material (e.g. an OEL for graphite being given for CNT) when it is unlikely to be accurate.

37 When looking rather generally at the current, large toxicological evidence base across a wide breadth of nanoparticles, it seems that:

- Many nanoparticles are likely to pose a low hazard at plausible exposures to the lungs.
- The skin is unlikely to be affected by the common nanoparticle types, which do not cross into the human body through skin to any significant extent.

38 These are broad generalisations taken on balance, but it has been shown that some highly toxic nanoparticles such as ZnO nanoparticles might adversely affect the lungs if there is on-going high exposure. In addition, there are special cases of particulate nanoparticles that might pose unusual hazards due to their novel and unusual properties which do not arise in nature. This includes long (>15 µm) nanofibres and nanotubes, low density "fluffy" nanotube bundles and large but very thin plate-like particles, all of which are large but with small aerodynamic diameters so that they are not dealt with by normal mechanisms.

39 Below are listed several attributes in the form of questions that may infer toxicity to nanomaterials and as such, the presence of one or more of these physico-chemical characteristics may suggest increased hazard potential. (Inclusion here is based upon generalisations and intended to help inform as to the potential risks and should not be seen as a replacement for robustly derived OELs if available.)

- *Is the particulate classified as a CMTR (carcinogens, mutagens, teratogens and reproductive toxicants) or sensitizer?*

If the bulk or parent version (if it exists) of a nanomaterial is already classified as a CMTR or skin/respiratory sensitizer, there is a high likelihood that the nanoparticulate form will also demonstrate this toxic potential. Indeed due to their characteristically large surface area, the

nanoparticulate form may exhibit comparatively greater activity than that of the bulk compound and should therefore be considered as potentially hazardous.

- *Is the nanomaterial composed of reactive metal(s)? Is the nanomaterial photoreactive? Does the nanomaterial have a highly charged surface?*

The presence of reactive metals is known to drive the toxicity of various complex particulate mixtures such as welding fumes (McNeilly et al, 2004). Therefore a nanomaterial possessing a significant proportion of such metals (e.g. large amounts of catalyst remaining within unrefined carbon nanotubes) could be regarded as having a potentially hazardous component.

When exposed to light, photocatalytic nanomaterials (e.g. certain forms of TiO₂) can release free radicals (Konaka et al, 1999) that may generate toxicity by causing inflammation, oxidative damage and genetic damage Hirakawa et al, 2004; Carlotti et al, 2009).

The surface charge of a nanomaterial is known to influence its propensity to agglomerate/aggregate, but it can also play a prominent role during cellular uptake or interactions with charged molecules such as proteins.

These attributes, singly or collectively, can contribute to the surface activity of a nanoparticle and are potential drivers of toxicity. The combination of high surface area and high reactivity may lead to the formation of a “double hazard” (Duffin et al, 2007; Karlsson et al, 2009).

- *Is the nanomaterial highly acidic/basic?*

If contact with a nanomaterial leads to a substantial pH change away from the normal range of the biological environment at a point of contact (e.g. skin or site of deposition within the lungs), this could cause adverse effects. These could include local effects such as skin irritation/corrosion or, for example, cell death within the lungs leading to inflammation/oedema/fibrosis.

- *Is the (nano)material soluble?*

The solubility of a (nano)particle can have a positive and/or negative influence on its propensity to cause harm. Specifically if a particle is soluble in an aqueous environment but *does not* release toxic components, a progressive reduction/removal of dose will occur as the particle dissolves. However if the particle releases reactive or cytotoxic components such as toxic ions as it dissolves, its toxicity could increase.

An attribute of nanoscale materials is the potential for changes in physico-chemical characteristics, including solubility, compared to the bulk material; e.g. bulk silver is insoluble, but nano-silver releases free silver ions in aqueous solutions by dissolution. Therefore the contention that since the bulk material is insoluble, the nanomaterial is also insoluble is not necessarily correct. As such when considering the hazardous nature of a material, it is pertinent to consider both the insoluble (particle) and soluble components in the hazard assessment.

- *Is the nanomaterial fibrous (i.e. possess a high aspect ratio)?*

There is concern that fibrous nanomaterials such as carbon nanotubes or nanowires may represent a similar danger to health as hazardous fibres such as asbestos, refractory ceramic fibres or certain man-made vitreous fibres (MMVFs). The basis for this is the morphological similarity between these fibres and newly developed high aspect ratio (fibrous) nanomaterials (HARN). However if the fibre hazard paradigm is to be enacted, certainty is needed that it is a fibrous sample that is being dealt with, i.e. it should meet the criteria of the definition of a fibre, such as that of the World Health Organisation (WHO).

The WHO defines a respirable fibre as an object with length greater than 5 µm, width less than 3 µm and length to width ratio (aspect ratio) greater than 3:1 (WHO, 1997). Those particles which do not meet these base criteria would not be considered as fibres and are unlikely to represent a fibre-type hazard (although they may still represent a particulate-type hazard). Within fibre toxicology, a fibre begins to generate difficulties with normal clearance mechanisms in the lung when its length prevents its full enclosure by those cells tasked with clearing such particles (alveolar macrophages). This is considered to be between 15-20 µm in length (Donaldson et al, 2010). A nanomaterial longer than 15 µm would therefore potentially frustrate clearance mechanisms if deposited in the distal lung and lead to hazardous effects similar to those associated with other harmful fibres. Due to the uncertainty around the identification of a clear length cut-off for harmful fibres, the WHO length criteria of 5 µm could be seen as presenting a suitably conservative approach.

Since generalisations should not be based purely on the substance type when considering the potential hazard of a particulate; not all fibrous nanomaterials will necessarily represent a fibre hazard as outlined above and not all nanomaterials typically thought of as particulate, always exist in particulate form. For example, not all carbon nanotubes are true fibres, as many form highly curled, dense bundles and are particulate in nature. Conversely, not all TiO₂ nanoparticles are particulates, since like many materials, it can be formed into wires (Hamilton et al, 2009) which could represent a fibre hazard. **It is therefore imperative that the true physico-chemical characteristics of the sample under consideration (and not just of the class of material) be established when considering the basis for hazard.**

- *Does the nanomaterial possess a low aerodynamic diameter yet one or more high aspects?*

As the basis for respiratory toxicity from fibres requires a low aerodynamic diameter for penetration into the distal airways yet a large physical aspect (e.g. fibre length or particle diameter), it is worth bearing in mind that other shapes, not just fibres, can possess these properties. Plate-like structures such as grapheme/graphite platelets can have a very large (>15 µm) diameter yet be very thin (<100 nm) and as such possess a low aerodynamic diameter (Sanchez et al, 2011), allowing them to be respirable. In addition, low density 'fluffy' bundles of fibres, often seen with carbon nanotubes, may also, due to their very low density, possess the potentially hazardous mix of low aerodynamic diameter with one or more high aspects, making clearance from the distal lung difficult. However much more research is needed into these particle types to understand if they are likely to represent a true hazard to humans.

Hazard Banding

40 As discussed above, the currently available toxicology data for the majority of nanomaterials would be considered as *Minimal* or *Suggestive* and this is incompatible with the development of an OEL (Figure 1). As a practical interim solution to aide in the risk assessment of such materials, a hazard and control banding approach could be utilised.

41 Hazard banding as an approach has been adopted within the pharmaceutical industry with early publications on the subject from the mid-1990s (Naumann et al, 1996). It was developed as a means to deal with the problem of the rapid development of new compounds for which few toxicological data existed. Indeed for some of these compounds, the mechanisms by which they had their effects were poorly understood, yet they were becoming increasingly potent with unknown short and long term health effects. A practical approach to mitigating the risks associated with such unknown compounds was to classify them based on limited toxicological data into bands, which inform as to the relative hazard, maximum exposure levels and are aligned with control schemes. This would mean in practice that a nanoparticle classed as "highly hazardous" could only be handled within

full contaminant and associated low airborne mass concentration exposure limit, whilst those classified as “low hazard” (e.g. an airborne mass concentration in line with the nuisance dust limit of 10 mg/m³) could be handled with good ventilation and appropriate PPE.

42 A problem equally as relevant to nanomaterials as to chemicals and pharmaceuticals is what to do with materials for which *no* information exists. An approach may be to use “physico-chemical or structural alerts”, such as those discussed earlier, many of which are incorporated into control banding tools. Identification of such alerts may suggest a basis for hazard and promote a nanoparticle up the category scheme, necessitating tighter controls and exposure measures. Another approach is to adopt a default *preliminary* category associated with sufficient exposure control measures that would protect workers should a compound later be shown to be toxic. Movement out of such a category would be based upon toxicological evidence to allow its transfer to a lower or higher hazard category as appropriate. The latter approach is conservative whilst the former allows a case-by-case basis that reduces the number of non-toxic nanoparticles being encumbered by what may subsequently be shown to be excessive control methods.

43 Whilst it is possible to identify some nanoparticles in relation to their hazard (e.g. certain forms of TiO₂ considered as low hazard), the hazard banding approach is still under development and has yet to be validated for nanomaterials. Further development as well as expert and regulatory agreement of the criteria for inclusion of nanoparticles into different bands are required.

Exposure Control

44 UK and European law requires workplace exposure to substances hazardous to health to be controlled adequately. This applies to nanomaterials particularly where there is uncertainty about the risk. To achieve adequate control involves applying “good control practice”, which is a consensus view of hardware, systems of work and other measures that need to be put in place to control the risk.

45 An employer’s overriding duty and first priority is to consider how to prevent employees being exposed to substances hazardous to health (including nanomaterials) by all routes. Employers who do not do this are failing to comply with a fundamental requirement of COSHH. The principles of the hierarchy of controls, which is based on inherent reliability and likely effectiveness, should be applied. The duty to prevent exposure should be achieved by measures other than the use of personal protective equipment.

Risk Assessment

46 A risk assessment must be carried out before an employee is allowed to work with nanomaterials. This risk assessment must be a suitable and sufficient assessment of the risk to health caused by the work. The HSE booklet “A step by step guide to COSHH assessment” describes in general terms the procedures to be followed in making an assessment. The COSHH general Approved Code of Practice (ACOP) also gives guidance.

47 Assessment of the risk should include identifying all potential sources of exposure. An action plan /check list for assessment would involve addressing the questions:

- Where are nanomaterials likely to be generated/synthesised etc?
- Is exposure likely?
- Who is likely to be exposed?
- Can the exposure be prevented?

- If the exposure cannot be prevented, estimate the potential level of exposures.

48 Work activities involving nanomaterials which require special attention when assessing exposure include:

- Handling of particulate nanomaterials.
- Manufacturing of nanoparticles (especially production of nanoparticles in a gas phase) and associated maintenance of equipment.
- Machining of materials containing nanoparticles (e.g. sawing, polishing, grinding).
- Spraying of liquids containing nanoparticles.
- Processing nanoparticles in a liquid where a high energy output is involved.
- Waste disposal of all types of nanomaterials.

49 In making the assessment, careful attention should be paid if there is a possibility of inhalation of the particulate nanomaterials.

50 In all cases, the assessment should be written down and reviewed if circumstances change or new information becomes available on the hazard of the nanomaterials being used.

Prevention and control of exposure

51 Having made an assessment of the risk from exposure to nanomaterials, employers must ensure that such exposure is either prevented, or if that is not reasonably practicable, adequately controlled.

52 Employers need to consider the following precautionary measures in their prevention and control procedures, and adapt them to suit their circumstances. Employers should arrange to review regularly the adequacy of the precautions taken, particularly if the circumstances of use change or in the light of new technical developments or information on the nanomaterials.

Prevention of exposure: Substitution

53 As with all substances potentially hazardous to health, the employer must give first priority to preventing workers being exposed to nanomaterials. This can be achieved in a number of ways, for example by using a substitute material or process, which does not involve nanomaterials, or by changing the method of work. In considering substitution, it is important to take account of any hazards of the substitute materials or process and balance the risks these might present against the benefits. More guidance is given in the HSE booklet 7 “Steps to successful substitution of hazardous substances”.

Workplace Exposure Limits

54 At the time of preparing this guidance, there are currently no UK legal Workplace Exposure Limits (WELs) specific for any nanomaterials. Therefore, in compliance with COSHH, the potential for exposure should be eliminated or strictly controlled to as low a level as is reasonably practicable.

55 There have been many references made in the literature to proposed limits. None of these limits are based on health effects; some ascertain they are achievable with good control practices; others are based on extrapolation from toxicological studies. In the United States, the National Institute for Occupational Safety and Health (NIOSH) has issued a recommended occupational

exposure limit (REL) for CNTs, but currently there is no legal basis to use these limits in the UK. These limits should be used with extreme caution. It should also be noted that measuring nanomaterials in the workplace is a challenge and there is considerable debate on which metric to measure.

56 It should be noted that the UK WEL for airborne ‘Carbon Black’ of 3.5 mg/m³ (3500 µg/m³) is **not** considered appropriate for carbon nanotubes.

57 Measurement of airborne particulate nanomaterials is not a simple, quick or straightforward task and therefore the preferred/practical option **in most research environments** is to prevent potential exposure with rigorous containment via engineering controls rather than an extensive airborne nanomaterial monitoring regime.

Approaches to selecting control measures

58 Several approaches may be taken to identify the necessary control measures required to prevent exposure to particulate nanomaterials in the laboratory and workplace. Traditional approaches for risk assessment of substances cannot always be applied to all nanomaterials due to the missing data or uncertainties with existing information. An alternative approach is the utilisation of control banding, which is a simplified approach to evaluate the risks from activities and the substances they involve into bands according to the potential for exposure and the hazard. For each risk band, control measures are then suggested. A number of tools are being developed (Table 1), albeit with important assumptions and limitations, which may help *inform* the assessment and management of risks from working with all nanomaterials and indeed other chemical substances.

Table 1: Examples of current control banding tools being developed for nanomaterials

Name	Type	URL
Precautionary Matrix	Risk Prioritisation	http://www.bag.admin.ch/themen/chemikalien/00228/00510/05626/index.html?lang=en
NanoCB Tool	Control Banding	http://www.controlbanding.net/Home.html
ANSES nano	Control Banding	http://www.afsset.fr/index.php?pageid=2820&parentid=805
Stoffenmanager Nano 1.0	Risk Prioritisation	http://nano.stoffenmanager.nl/
NanoDafer	Risk Evaluation (semi-quantitative)	http://nanosafer.i-bar.dk/

N.B. These tools have been developed independently of each other and are not standardised. This may lead to different outcomes from each model for the same data inputs.

59 The control banding approach of COSHH Essentials can be applied to nanomaterials. This is a tried and tested, robust approach for many chemical hazards, although it is important to acknowledge that there currently are no COSHH Essential control sheets for nanomaterials, but development is on-going.

Control of exposure to particulate nanomaterials

60 Use of good laboratory/good workplace practice is a pre-requisite to controlling exposure to all substances hazardous to health. Where information on the toxicity of a specific particulate nanomaterial is unknown or unclear, a precautionary approach should be adopted; i.e. it should be assumed, until proven otherwise, that the specific particulate nanomaterial represents a hazard to health.

61 Therefore, wherever reasonably practicable, exposure to particulate nanomaterials by all routes (inhalation, dermal and ingestion) should be eliminated or controlled by the use of engineering controls. If total prevention of exposure to particulate nanomaterials is not reasonably practical, the duty under COSHH is to reduce exposure to the lowest reasonably practicable level. (Appendix 2 shows a particulate nanomaterial control measures selection flowchart).

62 If engineering controls and good laboratory/good workplace practice are not adequate to control exposure, consideration should be given to using additional controls, such as respiratory protective equipment to prevent inhalation. Whatever system is chosen, there is a need to check that it is and remains effective.

63 In most cases the principle potential exposure route to particulate nanomaterials in the laboratory or workplace is via inhalation. Therefore, wherever possible the release of airborne particulate nanomaterials should be minimised or prevented by the use of appropriate processes, practices, systems and engineering controls.

Inhalation risk

64 Where there is a risk of particulate nanomaterials becoming airborne, the following measures should be used to control and prevent exposure:

- Where possible:
 - Minimise the quantity of particulate nanomaterials in use at any one time.
 - Minimise the number of people potentially exposed.
 - Minimise the potential exposure time.
- Ensure that all those potentially exposed to particulate nanomaterials have had suitable and sufficient information, instruction and training.
- Use engineering controls such as Local Exhaust Ventilation (LEV) to control airborne exposure.
- Avoid contact with the skin. Always wear suitable disposable, single-use gloves.
- Where dust exposure from contamination of work clothing could be significant, use clothing made from a low dust-retention and low dust-release fabric.
- Keep all bottles/vessels containing particulate nanomaterials sealed when not in immediate use since it has been shown that the action of opening vessels containing free particulate nanomaterials can cause them to be drawn from the vessel so that they become airborne.

- Where possible, keep the particulate nanomaterial wet or damp, or use slurries, and avoid energetic processes that might generate airborne dusts or aerosols to reduce the risk of particulate nanomaterials becoming airborne.
- Use a damp sheet of paper towel or tissue on the bench when weighing out particulate nanomaterials and dispose of it in a sealed plastic bag whilst it is still damp.
- Use a damp paper towel or tissue to wipe up spilt particulate nanomaterials and dispose of it in a sealed plastic bag whilst it is still damp.

Dermal and ingestion risk

65 Where there is a risk of particulate nanomaterials contacting the skin, the following measures should be used to control and prevent exposure:

- Where possible:
 - Minimise the quantity of particulate nanomaterial in use at any one time.
 - Minimise the number of people potentially exposed.
 - Minimise the potential exposure time.
- Ensure that all those potentially exposed to particulate nanomaterials have had suitable and sufficient information, instruction and training.
- Use engineering controls such as LEV to control airborne exposure.
- Avoid contact with the skin. Always wear suitable disposable, single-use gloves.
- Change the disposable gloves after every task.
- Ensure gloves are removed in a safe manner and disposed of safely.
- If possible, use instruments/tools to prevent contact with the skin.
- Good housekeeping is important with easy to clean surfaces, containment of spills and keeping the workplace surface clean using wet wipes.
- Good personal hygiene/skin care is also important; suitable welfare facilities should be provided.
- Use a damp sheet of paper towel or tissue on the bench when weighing out particulate nanomaterials and dispose of it in a sealed plastic bag whilst it is still damp.
- Use a damp paper towel or tissue to wipe up spilt particulate nanomaterials and dispose of in a sealed plastic bag whilst it is still damp
- Always wash hands before leaving the laboratory/work area.

Engineering Control Measures

66 Engineering control measures will vary depending on the requirements of each workplace. It may be necessary for those working with particulate nanomaterials to use a combination of methods to control exposure. These methods range from total enclosure of the process and automatic handling techniques, to partial containment by LEV, such as extracted enclosures and fume cupboards. Total enclosure or partial enclosures such as fume cupboards will be reasonably practicable for many operations with particulate nanomaterials, including manufacture/synthesis and weighing. For cutting, sawing or polishing, simpler extracted enclosures and other LEV devices such as capturing/receiving hoods or down-draught benches may be appropriate. Particulate nanomaterials have also been shown to be captured by electrostatic collectors. However, certain work activities may lead to higher potential exposure and therefore additional control measures may be necessary.

67 All LEV equipment should be designed and installed to a high standard (see HSG 258).

68 Wherever reasonably practicable, the exhaust air from an LEV system should be filtered through a High Efficiency Particulate Air (HEPA) filter, preferably H14, to remove the airborne particulate nanomaterials before venting to a safe place outside the building. This is particularly important when handling HARNs such as carbon nanotubes or other fibrous/rod like nanomaterials. **If it is not reasonably practicable to vent the exhaust air to a safe place outside, it must never be re-circulated directly back into the workplace unless it has been effectively filtered to remove airborne particulate nanomaterials by at least one HEPA H14 filter (see Appendix 1).**

HEPA Filtration Efficiency

69 HEPA filters HP14 are designed to remove at least 99.97% of airborne particles with a diameter of 300 nm, which is classically regarded as the Most Penetrating Particle Size (MPPS). Larger and smaller particles may be filtered with even higher efficiency. Recent studies indicate that HEPA filters of this grade are reasonably efficient at capturing the relatively limited number of particulate nanomaterials (as small as 2 nm in diameter) tested. It should be noted that different grades of HEPA filter have differing efficiencies in the nanoparticle range. In addition, different particulate nanomaterials may have differing MPPSs and penetration rates depending on their shape, density and charge.

70 Ultra Low Particulate Air (ULPA) filters are designed to remove 99.999% of airborne particles with a diameter of 120 nm, but to date, little information is available on their performance with particulate nanomaterials.

Local Exhaust Ventilation (LEV)

71 The most effective class of LEV are enclosures. In the laboratory setting there are generally two types: full or partial. Full enclosures (e.g. a glove box with HEPA filtration) are the most effective as they provide physical separation between the worker and the material. However, their inherent features can make them impractical as a control option and therefore partial enclosures are frequently used. These may be designed specifically for the process or be commercially available units. Examples of partial enclosures suitable for handling particulate nanomaterials include: HEPA-filtered fume cupboards, HEPA-filtered containment cabinets or a HEPA-filtered microbiological safety cabinets (MSCs). Using double HEPA-filtered cabinets increases the level of protection and can provide a safe means of carrying out filter changes.

72 The small size and "low inertia" of particulate nanomaterials means they move with the air generated by the process in a manner more akin to gases than conventional particles. Therefore correctly designed LEV systems should be an effective control measure.

73 The effectiveness of any control measure cannot be automatically assumed when handling particulate nanomaterials. Respirators, HEPA-filtered cabinets and most importantly fume cupboards were not specifically designed for this task, and so evidence should be sought as to their effectiveness before use. For newer installations, information may be sort in the LEV commissioning report (see HSG 258 and BS EN 14175).

74 It is important to make sure that the LEV achieves and maintains adequate control of exposure at all times. The system requires regular maintenance/periodic monitoring to ensure controls are working and thorough examination and testing “once a year” (COSHH allows a maximum of 14 months between tests). In most circumstances, face velocity measurements will suffice, but a smoke test will show whether the LEV is truly effective. Furthermore, if a smoke test is performed with the process/operation running, it will show:

- The size, velocity and behaviour of airborne contaminants.
- The capture zones and boundaries.
- Whether containment is maintained within the hood.
- Draughts, their direction and size.
- The general movement of air around the hood.
- Eddying and encroachment into the operator’s breathing zone.

75 If there is any doubt about the capability of a fume cupboard, then it may be necessary to carry out a full containment test, as detailed in BS EN 14175-4:2004.

76 All users should be trained in how to check and use the LEV and records should be kept of all the daily, weekly, monthly and annual LEV checks.

Ducted Microbiological Safety Cabinets (MSCs)

77 Ducted MSCs can be used to handle particulate nanomaterials in a similar way to other HEPA-filtered containment cabinets. A Class I MSC operates in a similar way to a fume cupboard and protects the worker by drawing air through the front opening. Class II and III MSCs provide protection for both the user and the material in the cabinet. All these cabinets exhaust air through a HEPA filter.

78 It should be noted that Class II MSCs are NOT suitable for handling HARNs and are only suitable for handling small (<1 g) quantities of particulate nanomaterials because they re-circulate up to 70% of their air inside the cabinet and are only specified to a containment level of 1/100,000.

Ductless re-circulating HEPA-filtered containment cabinets and re-circulating MSCs

79 Ductless re-circulating HEPA-filtered containment cabinets and MSCs that “re-circulate” air back into the room from the cabinets interior through a HEPA filter, can be used for small quantities (<1 g) of particulate nanomaterials **in the absence of hazardous vapours or gases**. However, the use of a ductless re-circulating cabinet or enclosure to control any hazardous substance must be subject to rigorous risk assessment and should only be considered where external venting to a safe place outside is not reasonably practicable. The containment cabinet should be set aside for use with particulate nanomaterials or chemically similar materials because some other chemicals, particularly those with the potential to evolve corrosive vapours or fumes, may affect the effectiveness and integrity of the fitted filter.

80 **HEPA-filtered re-circulating cabinets do NOT absorb or capture fumes, gases or vapours, for which external venting to a safe place would be required in addition to the HEPA filter.** If corrosive vapours or fumes could be generated, a glass fibre rather than cellulose HEPA filter should be used and the exhaust vented to a safe place outside.

81 The International Organization for Standardization Technical Report (ISO/TR 12885) on nanotechnology proposes a series of qualifications on the use of MSCs based on their mode of operation and the quantity of nanomaterial that could be safely handled in them (Appendix 1).

82 If using a re-circulating safety cabinet or re-circulating MSC, it should conform to BS7989:2001 3 and the following must be considered:

- The filter must be HEPA; charcoal filters alone must not be used¹.
- The cupboard should have a filter blockage warning/alarm.
- The cupboard must have a low airflow warning/alarm.
- How a saturated filter is to be safely changed.
- How the contaminated filter is to be safely disposed of (incineration is recommended).
- The cupboard must be subject to regular maintenance including a filter integrity test.
- The cupboard must be subject to thorough maintenance, examination and testing (including a filter integrity test) at periods not greater than fourteen months, and more frequently if the assessment identifies higher risk; every 6 months would be good practice.

Maintenance, examination and testing of control measures

83 Regulation 9 of COSHH requires that every employer who provides any control measure to meet the requirement of Regulation 7 shall ensure that it is maintained in an effective state, in an efficient working order and in good repair.

84 In order to comply with Regulation 9 it should be ensured that:

- All measures used to control exposure to nanomaterials are maintained in good working order and in good repair. (The manufacturer/supplier of plant should be able to help with appropriate information.)
- Competent persons undertake frequent visual checks and periodically carry out thorough examinations of equipment to ensure they are being maintained adequately.
- All LEV plant is examined and tested at least every 14 months (a record of such tests must be kept for at least 5 years after the date on which they were made).

85 Further general information about LEV is contained in HSG 258.

¹ Charcoal filters are designed to absorb vapours and fumes, for which they have a finite capacity. When the capacity is exceeded, contaminate is returned to the workplace. Charcoal filters alone are not designed for filtering solid materials and for these reasons the use of such systems should be avoided.

Personal Protective Equipment (PPE)

Eye protection

86 Suitable eye protection must be worn when handling any chemicals including particulate nanomaterials (minimum of close fitting safety glasses).

Respiratory protective equipment

87 There will be situations where other control measures are either not reasonably practicable or fail to achieve adequate control. In these circumstances, the use of Respiratory Protective Equipment (RPE) is a valid control strategy. RPE should only be used however when all other reasonably practicable measures have been taken but these have not, in themselves, achieved adequate control.

88 It must be emphasised that the use of RPE as a means of preventing exposure should be a last resort (COSHH) and must not be undertaken lightly or without full consideration of the practicality of using engineering controls.

89 Disposable masks (no less than FFP3 standard) are only suitable as a secondary precautionary measure against accidental “spillage” not as a first line of protection. Full-face P3 APF40 (Assigned Protection Factor 40) particulate respirators that protect the eyes and lungs are required for any work in an atmosphere containing airborne-engineered particulate nanomaterials.

90 All RPE, including disposable masks, must be suitable for the task, manufactured to the appropriate standard and face-fit tested for the individual by a competent face-fit tester.

91 Those using RPE should be trained in its use and if the equipment is re-usable, it should be regularly cleaned, checked to ensure that it remains effective and monthly maintenance records kept. For further information on the selection, use and maintenance of RPE, see <http://www.hse.gov.uk/coshh/basics/ppe.htm>.

Gloves

92 The gloves selected should be suitable and manufactured to an appropriate standard. For many particulate nanomaterials, good quality, disposable, single-use gloves should be adequate. However consideration must also be given to other chemicals used in the procedure/process. Organic liquids, including solvents, can not only permeate through gloves quite quickly in their own right but may facilitate the penetration of small particulate nanomaterials through gloves.

93 Glove material thickness is a major factor in determining the diffusion rate of chemicals through gloves and consideration may need to be given to wearing two layers of disposable gloves for some materials. Guidance on choosing the appropriate gloves to protect skin from a variety of substances can be found at <http://www.hse.gov.uk/skin/employ/gloves.htm>.

94 Currently the only criteria that can be readily accessed to validate gloves as potentially suitable for use with particulate nanomaterials is the virus penetration test (ASTM F1671-97b/ISO 16604), which uses a 28 nm diameter bacteriophage. If the risk assessment indicates that latex gloves are the safest choice, then only low protein, powder-free gloves should be used.

95 All those working with particulate nanomaterials should be properly trained in how to put on and remove gloves without contaminating themselves. Guidance on removing single-use gloves can be found on the HSE training video, available at: <http://www.hse.gov.uk/skin/videos/gloves/removegloves.htm>.

Protective clothing

96 When working with particulate nanomaterials, suitable lab coats, coveralls or where appropriate, disposable overalls should be worn. Provision must be made to allow clean overalls/laboratory coats to be put on and dirty ones removed in a manner that does not contaminate the individuals or the general workplace.

97 If dust exposure from contamination of work clothing could be significant, clothing made from a low dust-retention and low dust-release fabric such as polyethylene textiles is recommended. The European Nanosafe 2 project reported in 2008 that particulate nanomaterials can permeate through some intact disposable overall materials and by implication, woven reusable materials. The Nanosafe 2 report recommended non-woven Tyvek/Tychem polyethylene overalls for use with particulate nanomaterials in preference to paper or cotton.

98 If re-usable laboratory coats or overalls are used, provision should be made for their regular laundering and the prevention of secondary exposure. (In the event of a “one-off” gross contamination, consideration should be given to treating even “re-usable” PPE as disposable.)

Cleaning spillages

99 The work area and all equipment should be thoroughly cleaned after use or following a spillage by wet-wipe cleaning.

- **Do not** brush.
- **Do not** use compressed air for cleaning.
- **Do not** use a standard vacuum cleaner.

100 If a vacuum cleaner is the only reasonable practical means of cleaning, it must be a **dedicated, commercial, HEPA-filtered** cleaner and the filter regularly changed under controlled conditions that contain the particulate nanomaterial dust for disposal as hazardous waste. The cleaner itself must only be used for this task and will need to be treated as hazardous waste at the end of its life, following the precautionary approach.

Specific Advice for High Aspect Ratio Nanomaterials (HARNs)

101 CNTs and some nanowires (as described in page 13) are substances of high concern and unless, or until, sound evidence is available on the hazards from inhalation, a strict precautionary approach should be taken to the risk management of all HARNs.

102 If the use of HARNs cannot be avoided, then the implementation of a risk management programme in the workplace can help to minimise the potential for exposure to HARNs. Such a programme should include the following:

- Assess the worker’s job and tasks to determine the potential for exposure.
- Use appropriate work processes, systems and engineering controls, and provide suitable equipment and materials to minimise the likelihood of release i.e. minimise the amount of HARNs produced, or produce HARNs in a form that reduces the chance of them becoming airborne. Where possible, use equipment that fully encloses the process.

- Control exposure at source by carrying out all tasks, including packaging for disposal, in a ducted fume cupboard with a HEPA filter, or in other suitable LEV fitted with a HEPA filter. When using other types of LEV, try to enclose the process as much as possible. Ductless, HEPA filtered safety cabinets and re-circulating HEPA filtered Class I or III MSCs can be used with small quantities of CNTs ,and other HARNs as long as they are subject to rigorous maintenance and checks are carried out to ensure they are effective at all times. See Appendix 2 for more information.
- Reduce the number of employees handling HARNs and minimise the level and duration of exposure and the quantities used.
- If possible, keep the material wet or damp to reduce the risk of it becoming airborne.
- Provide RPE for emergencies, and only for use in addition to other control measures. All employees who use RPE must be trained and have had face-fit testing performed. HSE recommends RPE with an assigned protection factor (APF) of 40 or higher.
- Provide personal protective equipment (e.g. gloves, non-woven coveralls). Use single-use disposable gloves where possible. Glove material thickness is a major issue in determining diffusion of particulate nanomaterials and therefore at least two layers of gloves are recommended when handling HARNs. If the risk assessment indicates that latex is the safest choice, then only use low protein, powder-free gloves. Provide protective clothing such as polyethylene textiles (e.g. Tyvek) which performs better and does not retain dust or allow dust to penetrate - do not use wool, cotton or knitted material.
- Consider maintenance, filter replacement, storage and disposal in risk assessments for the control of exposure to HARNs.
- Use 'wet-wiping' wherever practicable for cleaning and avoid the use of vacuum cleaners. If vacuum cleaners are the only reasonably practical option, they must be appropriately HEPA filtered and decontaminated before further use. Contaminated wet wipes should be double bagged and treated as hazardous waste.
- Emergency procedures should be in place to deal with spills, accidents and emergencies.
- Educate and train workers in the proper handling of particulate nanomaterials (e.g. good work practices) and keep records of all training carried out.

Information, Instruction and Training

103 To comply with Regulation 12 of COSHH, employers should give all their employees who may be exposed to nanomaterials at work, sufficient information, instruction and training to understand the risks to their health caused by potential exposure to nanomaterials and the precautions that should be taken to avoid or minimise exposure.

104 In academia, it is important that the person carrying out the research carries out risk and COSHH assessments and is trained in how to perform these tasks. A senior member of staff should check and sign them off, but should not write them *per se*. A central record of all health and safety training in COSHH and risk management should be kept within the department with or for students, and this can be used for future employment.

105 Employers should provide adequate supervision, particularly to new and inexperienced workers. The training should detail how control measures are to be used. Employees should be instructed to report any obvious defects in the control measures to their supervisor.

106 Where RPE is used, employees should be trained to check that it fits properly, and given clear instructions about when it should be used, serviced or, if it is disposable, thrown away.

107 Information, instruction and training should in particular enable employees to:

- Understand the risks to health arising from exposure.
- Use the control measures provided effectively.
- Use PPE effectively where necessary.

108 A record of all the information, instruction and training should be kept for each employee.

Monitoring

109 One of the general principles of risk management includes taking measures to prevent or minimise exposure of workers to nanomaterials and their releases into the environment. Monitoring is important to assess whether potential exposure occurs and whether the engineering controls are adequate. Exposure to nanomaterials can occur by ingestion, skin penetration or inhalation. However, inhalation is the primary route of exposure for airborne particulate nanomaterials. There is currently no consensus on which is the most appropriate metric or method to measure airborne nanomaterials in the workplace. Sampling strategies based on extensive real-time measurements and off-line characterisation of airborne engineered nanoparticles have been described in PD ISO/TR 27628:2007, ISO/TR 12885:2008, PD6699-3:2010 and Brower et al (2009). However, workplace exposure measurement surveys based on extensive monitoring using a large set of sophisticated equipment require training and expert knowledge.

110 Guidance documents, particularly those from ISO/BSI and NIOSH provide recommended approaches to undertaking exposure monitoring. NIOSH has proposed the Nanoparticle Emission Assessment Technique (NEAT) (Methner et al, 2010a, and b) and the German Chemical Industry Association (VCI) has also developed a tiered approach for the assessment of exposure to particulate nanomaterials in workplaces. Approaches based on simple to use, hand-held instruments have however been developed.

Limitations to monitoring

111 The monitoring of airborne particulate nanomaterials in the workplace is challenging due to the lack of portable and personal instruments that are selectively sensitive to engineered nanomaterials against a background of non-engineered nanomaterials (which can fluctuate). Background is defined as airborne particles present in the workplace and differs from engineered particulate nanomaterials/nanomaterials released during manufacturing, use or handling. It includes “ultra-fines” originating from different sources including urban pollution.

Instruments used

112 The sampling method described in Appendix 5 uses hand-held Condensation Particle Counters (CPC) and Optical Particle Counters (OPC). Hand-held CPCs and OPCs measure particle number concentrations in the size range from 10-20 nm to 1 µm and 0.5 µm to about 15 µm or greater

respectively. They are portable, easy to use, cost effective fast response instruments capable of detecting transient releases. An electrostatic precipitator or a suitable filter substrate should be used to collect samples for analytical EM analysis.

Sampling strategy

113 The protocol described in Appendix 5 is designed to be a pragmatic first stage approach to rapidly assess particle release and whether the control measures or changes implemented are effective. It requires at least a CPC, OPC and a sampler for subsequent EM analysis. All these instruments should be placed close to the task. Another CPC and OPC, positioned away from the task/process, can also be used. See Appendix 5 for more information.

114 It is important that the background level of nanomaterials is established before any production or processing of the nanomaterial is started. This is because there is a natural background level of nanomaterials in the air, the amount of which will depend on the location.

Limitations

115 As the hand held CPC and OPC instruments in their basic form give no or limited size discrimination in the size range detected, the source must be “detected” by increased in particle counts relative to the background, over a wide size range. More sophisticated instruments are available which offer much improved size discrimination which may help to better define the source but still rely on a comparison to the background count. Off-line EM analysis of the particles collected can confirm the presence or absence of the particles of concern. The performance and limitations of real-time instruments and samplers used for the monitoring of airborne particulate nanoparticles and the use of the data derived from them are not fully understood and is an area of active research. The protocol describes “current best practice”; however, given the developmental nature of this field in doubt, this approach should be supported by external expert advice where necessary.

Health Surveillance

116 On-going research on the hazards of engineered particulate nanomaterials is needed along with the continual reassessment of available data to determine whether specific medical screening is warranted for workers who are producing or using particulate nanomaterials.

117 HSE proposes that best practice would involve keeping a record of all those staff who are working with particulate nanomaterials via the equivalent of a COSHH work activity record form, in a similar way to other substances of concern. Alongside such records of work activity, the type of particulate nanomaterials handled, the duration of work with the material, and the exposure scenarios should be documented. An example of a work activity record can be found in Appendix 4.

118 Health screening and health surveillance *specific* for hazardous particulate nanomaterials are not practical at the present time due to a lack of information about anticipated health effects and suitable biomarkers.

119 The health hazards related to the material, irrespective of the nanoscale form, should still be considered as part of the usual COSHH risk assessment. This should be informed by considering the likely routes of exposure for the material of concern.

Disposal of Waste Nanomaterials

120 There is currently no waste regulatory framework in the UK specific for nanomaterials. Nonetheless, the Environmental Protection Act 1990 (Duty of Care) and Waste (England and Wales) Regulations 2011 (in Scotland, the Waste Management Licensing Regulations 2011, and in Northern Ireland, the Waste Regulations (Northern Ireland) 2011) apply.

121 The responsibility under UK law of any individual who is the holder of controlled waste is to ensure that the waste is managed properly, is recovered or disposed of safely, does not cause harm to human, animal or plant health or pollution of the environment, and is transferred only to someone who is authorised to receive it. However, not all nanomaterial waste will be classed as “hazardous waste”; for example, nanomaterials bound in a solid matrix or on a surface are unlikely to be hazardous. It is recommended that materials that contain nano pores (e.g. a surface template for nanomaterial deposition) are not considered as nanomaterial waste and disposal of these materials should follow standard hazardous waste disposal routes where applicable.

122 For larger consignments of waste nanomaterials (for example, from manufacturing), see PAS 138:2012.

123 The fate of nanomaterials in the environment, an obvious concern (RSC, 2006) is outside the scope of this guidance: however, a summary is available (CEP 2008).

124 Determining the method of waste disposal for nanomaterials is dependent on the nature and character of the nanomaterial waste; for example, whether the nanomaterial waste is in solid or liquid form. Raw nanomaterial presents a greater hazard than a solid matrix impregnated with nanomaterial owing to the increased risk of exposure. It is important that nanomaterial waste is identified and characterised (for example, dust filters contaminated with CNTs or HARNs, paper tissues impregnated with colloidal silver, metal oxide nanomaterials on carbon black), in order to determine which controls are needed to reduce the risk of exposure.

125 Drawing on previous guidance (MIT, 2008) nanomaterial waste can be broadly classified into the following waste streams:

- Pure nanomaterials (for example, CNTs).
- Items contaminated with nanomaterials (for example, wipes/paper towels).
- Liquid suspensions containing nanomaterials (for example, colloids).
- Solid matrices with nanomaterials that are friable or attached to the surface.
- Nanomaterials embedded in a solid matrix that are unlikely to be released on contact with air or water: i.e. the nanomaterial is immobilised.

126 The level of controls necessary to dispose safely of nanomaterial waste will depend on its nature. Unless there is evidence that the materials to be disposed of do not present any hazards, a **precautionary approach** should be taken for handling, packaging and disposal. Waste should be disposed of in such a manner that the risk of exposure to the nanomaterials is minimised.

127 It is recommended that waste nanomaterials or waste containing nanomaterials is double-bagged or doubly contained, labelled, and sealed in preparation for disposal. (*A consensus view OECD 2010*).

Preparation of nanomaterial waste prior to disposal

128 The risk of exposure to hazardous particulate nanomaterial waste must be either prevented or controlled; wherever possible, particulate nanomaterial waste should be either immobilised or contained. The disposal of nanomaterials irreversibly embedded in substrates or non-soluble media may be risk assessed separately following a precautionary approach.

129 Containment can be achieved by employing suitable, sturdy, compatible containers (for example, plastic, clip top containers), which prevent the escape of nanomaterials. Containers must be clearly labelled, providing a description of the waste and including the hazardous properties (either known or suspected).

130 In general, as well as the particulate nanomaterials, laboratory consumables such as paper towels, wipes, disposal gloves and suits, blotters and other moderately contaminated items should be double-bagged in preparation for disposal (i.e. transfer to the waste contractor for incineration). It is recommended that:

- Prior to disposal, the contaminated waste is placed in a sealable, plastic bag inside a fume hood/ biosafety cabinet.
- The sealed bag should then be placed inside another sealable, plastic bag and clearly labelled identifying the contaminated material.

131 It is suggested that where possible, contaminated liquid and solid waste is treated in an appropriate way to inactivate the nanomaterial (OECD, 2010). For example, contaminated liquid waste can be placed in a waste solvent stream (ultimately incinerated), fixed in a resin (Cornelissen, 2011) or adsorbed on to a solid substrate (for example, silica or carbon). Other examples of inactivation include: aggregating the nanomaterial in solution (for example, by centrifuging gold nanomaterials), or dissolving the nanomaterial in solution (for example, treating silver nanomaterials with aqua regia (a mixture of hydrochloric acid and nitric acid)). Solid nanomaterial waste can be included in existing solid hazardous waste streams, for example, mixed with waste silica (hazardous by virtue of potential inhalation) and double-bagged, sealed and transferred into a suitable sealable container (for example, a metal or plastic clip top drum).

132 Where surfaces or materials have been decontaminated (for example, wiped or washed down), producing a contaminated residue, it is recommended that the resulting residue/waste is treated as chemical waste (hazardous waste) (Cornelissen, 2011).

133 Nanomaterials should not be disposed of via normal (non-hazardous) disposal routes (through normal waste to landfill or drains) unless it can be demonstrated that disposal via these waste streams is safe and does not contravene environmental legislation. The **precautionary approach** has been generally adopted: no free nanomaterials should enter any non-hazardous waste stream or be disposed of via the drains (Cambridge, 2011).

Disposal by waste contractors

134 There is a legal obligation to comply with the Environmental Protection Act 1990 (Duty of Care) which requires that any waste for disposal should be fully described and this should include the presence of nanomaterials where there is any uncertainty to the risk they might pose. Further information is available from www.environmental-agency.gov.uk/netregs/62529.aspx.

135 The Environmental Agency guidance (EA, 2011a), which has recently been amended to reflect the revised Waste Framework Directive 2008, identifies whether waste is hazardous or not; if there is

insufficient evidence to demonstrate that the waste is non-hazardous, then according to the EA's guidance, the waste is classed as 'hazardous'.

136 The EA guidance (EA, 2011b) states threshold limits of $\geq 0.1\%$ for both very toxic (T⁺)^{‡*} substances by inhalation or skin absorption and Category 1 & 2 carcinogens, and a limit of $\geq 3\%$ for toxic materials by mass in 'bulk'. It is yet to be determined if this approach is applicable to nanomaterial waste. It has been suggested [PD 6699-2:2007] that most nanomaterial waste will fall into either "H5" or "H6" waste categories, i.e. 'harmful' or 'toxic' respectively if inhaled, or ingested, or adsorbed through the skin. In some cases, ascribing waste to either "H7" (carcinogenic) or "H13" (sensitizing) categories may be applicable as well.

137 Incineration of solid waste containing nanomaterials has been identified as the "conservative option" even though the nanomaterials are present at low levels (<1%) (HSE, 2004). With respect to CNTs, high temperature (>500 °C) incineration is the recommended method of disposal (HSE, 2009).

Table 2: Summary of treatment and control conditions for waste nanomaterials

Waste nanomaterial (NM)	Pre-treatment prior to disposal	Containment	Level of engineering controls	Disposal method
Raw NM (free nanoparticles)	Wet/moisten	Double	Inside a hood or glove box	Incineration
Contaminated solids (laboratory consumables)	Wet/ moisten if necessary	Double bag (plastic, sealable)	Inside a hood or glove box	Incineration
Liquid solutions (colloids/blends/QM Dots)	Mix with solvent waste stream.	Drip tray/funnel	Inside a hood	Incineration
	Aggregate nanoparticles	Vial/container/ drip tray	Inside a hood, and/or contained in a centrifuge.	Mix with solid waste. Incinerate
	Dissolve NP (form ions)	Vial/container/ drip tray	Inside a hood	Either mix with other soluble waste or dilute to drain.
NM bound in resin in or polymer	As for liquid solutions or package.	As for liquid solutions or double containment.	Inside a hood	Incineration
NM in a solid matrix but friable	Wet/moisten	Double containment	Inside a hood	Incineration or licensed landfill.
NM in a solid matrix not friable	None	Single containment	General ventilation	Incineration or licensed landfill.

^{‡*} Note: 'Very Toxic,(T⁺)' under Global Harmonised System (GHS) \equiv Acute Categories 1&2 and 'Toxic, (T)' \equiv Acute Category 3; Chronic Specific Target Organ Toxicity (STOT), (single and repeated exposure) Category 1; Germ Cell Mutagenicity, Carcinogenicity, Reproductive Toxicity are all Categories 1A & 1B.

Labelling and Signs

138 A requirement and/or standardised approach to labelling and safety signs for use with nanomaterials does not currently exist. It is recommended that a diligent approach is taken using, for example, existing risk and safety phrases and warning signs to provide adequate, relevant and specific information on any actual or potential hazards and safety risks.

139 Risk and safety phrases are used to convey information derived from the hazard, exposure and risk assessments, in Safety Data Sheets (SDS) and COSHH assessments. Derived from the Chemicals (Hazard Information and Packaging for Supply) (CHIP) Regulations, they are sequenced in numerical order and prefaced with “R” for risk phrases and “S” for safety phrases. The current lists of R and S phrases are available from sources including the UK Health and Safety Executive (<http://www.hse.gov.uk/chip/phrases.htm>) along with frequently used combinations.

140 The European Regulation (EC) No 1272/2008 on classification, labelling and packaging of substances and mixture (CLP) came into force in all EU member states, including the UK in 2010. The CLP Regulation adopts the Globally Harmonised System (GHS) on the classification and labelling of chemicals and will replace CHIP from 1 June 2015. Although the CLP hazard pictograms are very similar to the CHIP hazard symbols, they have a new shape, new design and a new colour.

141 GHS aims to bring together the various national and regional hazard communication systems that control the supply of hazardous chemicals and to ensure that information on physical hazards and chemical toxicity is available in order to enhance the protection of human health and the environment during the handling, transport and use of these chemicals. Activity associated with GHS may, in the future, provide a consistent approach for labelling of nanomaterials, but the assignment of risk and safety phrases will always be contingent upon consideration of the hazardous nature of the material where data are available, and in the absence of data, will require a precautionary approach.

142 The selection of appropriate hazard labels, signs or pictograms should be based on the available hazard information for the material. In the absence of information, a precautionary approach to labelling should be adopted.

143 *Ad hoc* signs or pictograms should be posted in areas to provide visual indication of local instructions or rules in place, for example, on storage cabinets, fume cupboards, instruments dedicated for use with nanomaterials. The content and format of the signs should be consistent with any in-house requirements.

144 Generic pictograms, adopting the format of the yellow/orange warning triangle, have emerged for “nanomaterial hazards” and whilst these have no official recognition by authorities, their use may be considered to provide a visual indication of the presence of nanomaterials, as appropriate. It should be noted that these generic signs do not provide any information on the nature of the hazard, and any known or suspected hazards (e.g. oxidising, explosive) should be adequately indicated.

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APPENDIX 1: Comparison of US Microbiological Safety Cabinet characteristics and applicability for nanomaterials

The International Organisation for Standardisation Technical Report (ISO/TR 12885) with respect to the use HEPA filtered cabinets for nanomaterials.

MSC Class	Face Velocity m/s	Airflow Pattern	Applications	
			Non-volatile Toxic Chemicals	Volatile Toxic Chemicals
I*	0.4	In at front then through HEPA to the outside or recirculate into the room through HEPA.	Yes	When exhausted outdoors ^{1,2}
II, A1	0.4	70% recirculated to the cabinet work area through HEPA; 30% balance can be exhausted through HEPA back into the room or to outside through a canopy unit.	Yes (minute amounts)	No
II, B1	0.5	30% recirculated, 70% exhausted. Exhaust cabinet air must pass through a dedicated duct to the outside through a HEPA filter.	Yes	Yes (minute amounts) ^{1,2}
II, B2	0.5	No recirculation; total exhaust to the outside through a HEPA filter.	Yes	Yes (small amounts) ^{1,2}
II, A2	0.5	Similar to II, A1, but has 100 lfpm intake air velocity and plenums are under negative pressure to room; exhaust air can be ducted to outside through a canopy unit.	Yes	When exhausted outdoors (Formerly "B3") (minute amounts) ^{1,2}
III	N/A	Supply air is HEPA filtered. Exhaust air passes through two HEPA filters in series and is exhausted to the outside via a hard connection.	Yes	Yes (small amounts) ^{1,2}

1. Installation may require a special duct to the outside, an in-line charcoal filter, and a spark proof (explosion proof) motor and other electrical components in the cabinet. Discharge of a Class I or Class II, Type A2 cabinet into a room should not occur if volatile chemicals are used.

2. In no instance should the chemical concentration approach the lower explosion limits of the compounds.

(Taken from Appendix A of ISO/TR 12885, Technical Report: Nanotechnologies - Health and safety practices in occupational settings relevant to nanotechnologies. Which in turn cites its source as the US Department of Health and Human Services publication 'Biosafety in Microbiological and Biomedical Laboratories, 2007')

*A Class I microbiological safety cabinet is similar in operation to a HEPA filtered fume cupboard or HEPA filtered cabinet, drawing in air through the front opening before HEPA filtering the exhaust.

APPENDIX 2: Particulate Nano-Material Control Measures Selection Flowchart



APPENDIX 3: Engineering Controls

Local Exhaust Ventilation (LEV):

Conventional ducted fume cupboards fitted with HEPA filtration and ducted microbiological safety cabinets may be used for HARNs, see below.

Fume cupboards

A fume cupboard is an enclosure designed to contain and exhaust vapours and gaseous contaminants generated inside it. A fume cupboard is a key engineering control device, therefore the selection of the appropriate fume cupboard design and the adherence to safe work practices are crucial to user safety.

For use with HARNs the fume cupboard exhaust air should be HEPA filtered, and wherever reasonably practicable vented to a safe place outside.

It is important that a fume cupboard complying with BS EN 14175-4:2004 is used and that the fume cupboard does not lose containment during normal use. In most circumstances, velocity measurements and smoke test will show whether the fume cupboard is effective. Smoke tests, with appropriate detection, can be used to investigate a number of problems, such as:

- irregular air-flow and eddy characteristics resulting in air movement out of the cupboard,
- the possible negative effects of equipment on airflow ,
- the possible negative effect of heat sources within the cupboard on airflow
- leakage from the cupboard or ducting.

However, if there is any doubt about the integrity of the fume cupboard then it may be necessary to carry out a containment test as in BS EN 14175-4:2004.

Installation of fume cupboards **must be only** be undertaken by those with knowledge of British Standard BS EN 14175-5: 2004 'Fume cupboards, recommendations for installation and maintenance'. In particular fume cupboards must not be sited:

- On heavy pedestrian traffic routes
- Adjacent to doors
- Adjacent to opening windows

As the above can cause air turbulence and wake affects that can affect the cupboards containment

- At the open end of a u-shaped laboratory bay, since a fire or explosion within the cupboard, may trap workers in the bay.

Microbiological safety cabinets

Ducted microbiological safety cabinets can be used*. The Class II and III microbiological safety cabinets, unlike the Class I type, provide protection for both the user and the material in the cabinet is working environment. All these cabinets exhaust air through a HEPA 14 filter.

***It should be noted that a Class II cabinet is not suitable for handling HARNs because it recirculates up to 70% of its air.**

Ductless recirculating HEPA filtered safety cabinets and recirculating microbiological safety cabinets

Safety cabinets and microbiological safety cabinets which recirculate air from the cabinets interior, through a HEPA 14 filter, back into the laboratory can be used for small quantities of HARNs in the absence of hazardous vapours or gases.

If using a recirculating safety cabinet or recirculating microbiological safety cabinet the following must be considered; Cupboard must conform to British Standard BS 7989:2001.3.

- The filter must be HEPA; charcoal filters alone must not be used[†].
- The cupboard should have a filter saturated warning/alarm.
- The cupboard must have a low airflow warning/alarm.
- How is a saturated filter to be safely changed?
- How is the contaminated filter to be safely disposed of? (incineration)
- Ensure that the filter integrity test is performed.
- Subjected to thorough examination and testing at periods not greater than fourteen months and more frequently if the assessment identifies higher risk; every 6 months would be good practice.

Charcoal filters are designed to absorb vapours and fumes, for which they have a finite capacity. When the capacity is exceeded, contaminate is returned to the workplace. Charcoal filters alone are not designed for filtering solid materials and for these reasons the use of such systems should be avoided.

Users should take steps to ensure that the standard of supervision, training, system of work and record keeping is up to date. The safety cabinet should be set aside for use with HARNs or chemically similar materials because some other chemicals may affect the effectiveness and integrity of the fitted filter.

NB: HEPA filtered recirculating cabinets do NOT absorb or capture fumes, gases or vapours, for which external venting to a safe place would be required in addition to the HEPA filter.

HEPA filter recirculating fume cupboards or cabinets can be used to control any potentially airborne 'dusty' hazardous substance as long as it is subjected to a rigorous risk assessment **BUT** should only be considered where external venting to a 'safe place' is not reasonably practicable.

APPENDIX 4: Record of Work Activity Form

Record of Work Activity Using Nanomaterials

COSHH Regulations require all individuals working with substances that can cause certain identifiable diseases or adverse health effects to be monitored. As a pre-cautionary measure the employer requires the completion of a Record of Work Activity for all individuals working with

- Nanomaterials (particles of approximately 100 nm or less in at least one dimension) with unknown toxicological properties.

For further information on the criteria for health surveillance see the HSE website:
<http://www.hse.gov.uk/coshh/basics/surveillance.htm>

Personal Details

Surname:

Forenames:

Male/Female:

Date of Birth:

N.I. Number:

Date commenced present job:

Permanent address:

Postcode:

Dept Tel No:

Status: Staff/Undergraduate student/Postgraduate student/Visitor/Other (Delete as appropriate)

Department:

Supervisor's name and contact telephone number:

Signed:

Date:

PLEASE COMPLETE SUBSTANCE DETAILS OVERLEAF

**THIS RECORD MUST BE KEPT BY THE DEPARTMENT FOR 40 YEARS
FOLLOWING THE INDIVIDUAL LEAVING EMPLOYMENT.**

SUBSTANCE DETAILS

Name of substance	Nature of hazard ¹	Physical state ²	Quantity, amount ³	Frequency/duration of use ⁴	Control measures in use ⁵

- 1 Carcinogen, mutagen, substance toxic to reproduction, respiratory sensitiser, skin sensitiser or '*nanomaterial of unknown toxicity*'
- 2 Powder, liquid, solid –this includes free nanoparticles, nanoparticles in liquid suspension or nanoparticles in a solid matrix
- 3 Include amount and units
- 4 Daily, weekly, monthly, rarely
- 5 Fume cupboard, laminar flow bench, Local Exhaust Ventilation (LEV), glove box or other form of containment, personal protective equipment (please specify)

APPENDIX 5: Sampling Protocol to assess release of particulate nanomaterials to the air

This protocol was designed to assess the release of particulate nanomaterials into workplace air allow the effectiveness of the controls to be checked and if necessary to confirm that exposure to the particles of concern was taking place. Positive results should trigger a review, and improvement of the control approaches used. Other more comprehensive strategies (e.g. Brouwer ref) are described in the literature which may give improved on-line discrimination. Given the developmental nature of this field of measurement, the detection limits for any of the strategies are not yet well-defined.

Real time measurements

1 An initial assessment without the process / task running should be carried out. A CPC and an OPC are moved around to investigate any other potential sources of non-engineered nanomaterials and the range in the background concentration. If possible these sources should be isolated or stopped during the monitoring period.

2 Measurements using a CPC and an OPC should be carried out before, during and after the activity under study takes place. The CPC and the OPC are stationary and positioned close to the worker's task (within an approximate 1m radius of the worker's head) taking care that they do not hinder or interfere with the workers' normal duties. Non-activity periods (before and after the activity period) should be monitored for at least 15 minutes if possible.

3 Measurements using a second CPC and a second OPC could be carried out before, during and after the activity under study takes place. The instruments are stationary and should be located at a distance from the activity, such that it measures airborne particle concentrations that are representative of the background concentration near the activity. A distance of at least 2 m is suggested. The non-activity periods (before and after the activity period) should be monitored for at least 15 minutes if possible.

4 A CPC could also be used with the telescopic probe attachment to monitor particle number concentration inside containment/fume cupboards during activity periods.

5 Be aware that any other extraneous sources of non-engineered nanomaterials such as: passing lorries/fork lift trucks, electric motors, smoke-generating systems, welding/soldering activities, open doors and windows can influence particle concentration readings greatly.

6 Smoke tubes, for the testing of fume-cupboards or local exhaust ventilation (LEV) efficiency, should not be used during the monitoring of the activities. It has been shown during previous studies that these can be a source of very high concentrations of airborne non-engineered nanomaterials.

7 All instruments should be calibrated at least every year and regularly checked to ensure consistent operation especially their performance to each other if several of the same instruments are used.

Collection of samples for electron microscopy analysis

8 A number of sampling techniques for the collection of airborne particles and subsequent electron microscopy analysis are available and include:

- Filtration onto filters or carbon films supported on transmission electron microscopy (TEM) grids using conventional sampling pump. TEM grids with a holey carbon film can be attached to filters. Filters can be pre-coated with gold for subsequent scanning electron microscopy (SEM) analysis.
- Precipitation using thermal or electrostatic precipitators.

9 A sampler should be positioned close to the activity/process and at a distance of at least 2m from the process/task (optional) alongside the CPCs and OPCs. Samples collected inside containments/fume-cupboards are also very useful for comparison with samples collected outside containments/fume-cupboards.

Record and contextual information

10 The times at which the monitors and samplers were started and stopped together with the sampler flow rates should be recorded. It is also critical that detailed contextual information of all activities before, during and after the task/process takes place are recorded as an increase in particle number concentrations from the real-time instruments may be unrelated to the task/process.

Interpretation of Results

11 Particle number concentration should be plotted and arithmetic means, minimum and maximum concentrations before, during and after the task/process should be calculated. A difficult question to answer is if an increase in particle number concentration means there has been a corresponding emission of engineered nano-objects from the task/process. For that, the “task/process” particle number concentration must be higher than the “background” particle number concentration and this increase has to be statistically significant. However some critical judgement should also be applied. The background may greatly fluctuate or it can gradually increase or decrease with time. The contextual information is important in this decision-making as well as knowing whether other sources of non-engineered nano-objects are present. The EM analysis of the sample will confirm the presence or absence of the engineered nano-objects and if necessary may be used to quantify the number concentration and size distribution.