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Series on the Safety of Manufactured Nanomaterials
No. 28

COMPILATION OF NANOMATERIAL EXPOSURE MITIGATION GUIDELINES RELATING TO LABORATORIES

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OECD Environment, Health and Safety Publications

Series on the Safety of Manufactured Nanomaterials

No. 28

COMPILATION AND COMPARISON OF GUIDELINES RELATED TO EXPOSURE TO NANOMATERIALS IN LABORATORIES

IOMC

INTER-ORGANIZATION PROGRAMME FOR THE SOUND MANAGEMENT OF CHEMICALS

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Environment Directorate
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT
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FOREWORD

The OECD Joint Meeting of the Chemicals Committee and Working Party on Chemicals, Pesticides and Biotechnology (the Joint Meeting) held a Special Session on the Potential Implications of Manufactured Nanomaterials for Human Health and Environmental Safety (June 2005). This was the first opportunity for OECD member countries, together with observers and invited experts, to begin to identify human health and environmental safety related aspects of manufactured nanomaterials. The scope of this session was intended to address the chemicals sector.

As a follow-up, the Joint Meeting decided to hold a Workshop on the Safety of Manufactured Nanomaterials in December 2005, in Washington, D.C. The main objective was to determine the "state of the art" for the safety assessment of manufactured nanomaterials with a particular focus on identifying future needs for risk assessment within a regulatory context.

Based on the conclusions and recommendations of the Workshop [ENV/JM/MONO(2006)19] it was recognised as essential to ensure the efficient assessment of manufactured nanomaterials so as to avoid adverse effects from the use of these materials in the short, medium and longer term. With this in mind, the OECD Council established the OECD Working Party on Manufactured Nanomaterials (WPMN) as a subsidiary body of the OECD Chemicals Committee. This programme concentrates on human health and environmental safety implications of manufactured nanomaterials (limited mainly to the chemicals sector), and aims to ensure that the approach to hazard, exposure and risk assessment is of a high, science-based, and internationally harmonised standard. This programme promotes international co-operation on the human health and environmental safety of manufactured nanomaterials, and involves the safety testing and risk assessment of manufactured nanomaterials.

This document is published under the responsibility of the OECD Chemicals Committee. It is intended to provide information on the outcomes and developments of the WPMN related to the safety of manufactured nanomaterials.

TABLE OF CONTENTS

COMPILATION OF NANOMATERIAL EXPOSURE MITIGATION GUIDELINES RELATING TO LABORATORIES

SECTION 1: INTRODUCTION

Nanotechnology is regarded as a future technology with increasing social and economical importance. However, despite of the new chances this expanding technology brings, the toxicological assessment of nanomaterials risks has not been completed comprehensively and/or at all in all cases. Therefore, the mitigation of the exposure to nanomaterials has great importance. Even though adequate workplace controls for the use of nanomaterials in large-scale production plants are applied, common standards do not exist yet. In addition to the wide use of a low number of high volume nanomaterials produced in large-scale, a high quantity of different nanomaterials are applied in a laboratory scale such as during subsequent processing of nanomaterials into various products in many laboratories including the research level.

For this reason, a particular interest exists regarding assessment criteria for the handling of nanomaterials in laboratories. Institutions as well as companies entering the nano-sector in all countries are producing and utilizing nanomaterials in a laboratory scale. Several strategies for assessment and implementation of protection measures must have been developed in those areas.

In the framework of the objective **Exposure Mitigation In Occupational Settings** [ENV/CHEM/NANO(2007)24/ADD2], one prioritized scope of the OECD's project on Exposure Measurement and Exposure Mitigation (SG8) was the implementation of the project "Compare exposure mitigation guidance for laboratories". This document is the outcome of this project covering activities and contributions of several OECD delegations.

The document was first developed by Germany within the German Federal Institute for Occupational Safety and Health (BAuA, Germany),[1] contributed to the precedent draft version of this document. Considering this background, this document is to be seen as one element within the frame of exposure mitigation in the handling of a wide range of nanomaterials with a large variety of production and manufacturing procedures.

Based on the fact that there is a large amount of literature available, this compilation is carefully focused on different available institutional guidelines. Such guidelines are compiled in a structured manner taken their nature (i.e. general, specific to certain manufactured nanomaterials and targeted to laboratories) into account.

[1] The first draft was developed in collaboration with other German organisations BGIA, BG Chemie, BASF, VCI, and Fundacentro (Brazil).

SECTION 2: SCOPE

This document aims to provide an overview over recently published guidelines regarding the usage of nanomaterials in a laboratory scale. It is intended to perform a compilation of exposure mitigation guidelines relating to laboratories that handle nanomaterials. This issue is of great importance since there are no globally standardized protection measures determined for nanomaterials. The insight in the state of the art of good practice for nanomaterials in laboratories may not only be important for research laboratories, but it can furthermore be of great interest for small industrial enterprises, which produce or process nanomaterials in a laboratory scale.

This document focuses on both pointing out publications of primary importance and representing a general overview of the international spectrum of publications in that topic. The guidance reports were mostly gained by research via internet. Research criteria used in this internet research were relevant search terms like ‘guidance’, ‘nanomaterial’, ‘research’ and ‘laboratory’. Further publications were obtained by selection of available collections of the participating authors. The guidance documents were chosen particularly on the basis of their level of detail in the respective aspects of protection measures.

This compilation is categorized by 1) specific nanomaterial guidelines relating to laboratories (herein after referred to as category S(pecific)), 2) general nanomaterial guidelines with regards/ applicable to laboratories (category G(eneral)), as well as 3) general laboratory guidelines with regards/applicable to nanomaterial (category L(aboratories)).

This aim was based on the assumption that only a very limited amount of specific nanomaterial guidelines relating to laboratories is published. However, an unexpectedly high number of specific guidelines were found. For this reason, this literature compilation focuses mainly on category S guidelines and is structured based on the different topics that are addressed. The statements of category S guidelines are supplemented by guidelines from category G and L, if indicated. Strictly speaking, guidelines of the categories G and L are only included if they provide additional information content in order to avoid a high degree of redundancy. An overview over the specific aspects of these guidelines can be found in Annexes I to XIII.

In this literature compilation, a range of different opinions shall be highlighted. These suggestions, which are mentioned in this compilation, reflect the respective positions of the authors.

SECTION 3: COMPILATION OF GUIDELINES FOR SAFE HANDLING AND USE OF NANOMATERIALS FOCUSING ON LABORATORIES

The compilation of guidelines is structured according to typical concepts of occupational safety. These concepts include the precautionary approach, risk assessment, categorization, safer manufacturing approaches, technical measures, organizational measures, personal protective equipment, medical surveillance, transport, waste disposal and documentation. The respective paragraphs are structured further according to the following three categories:

-Category S(pecific): specific nanomaterial guidelines relating to laboratories;
-Category G(eneral): general nanomaterial guidelines with regards / applicable to laboratories; and
-Category L(aboratories): general laboratory guidelines with regards/applicable to nanomaterial.

1. Precautionary Approach[2]

Given the deficit of knowledge on the environmental and health impact of nanomaterials, the application of the precautionary approach to the handling of nanomaterials is recommended by a number of specific nanomaterial guidelines relating to laboratories (S: AIST; CHS; DOE-NRSC; EPFL; Georgia Tech; HSE-a; ISU; MIT; NASA-ARC; NSF; OUHSC-IBC; TU Delft; UCI; UCSB) and by general nanomaterial guidelines (G: MHLW; NIOSH).

In one general guideline for nanomaterials, it is recommended that a precautionary approach guided by reference to the ‘precautionary principle’ be adopted in order to limit workplace exposure (G: Safe Work Australia). However, the authors mention that, once data about the health and safety risks have been determined and defined, the principle of ‘As Low As Reasonably Practicable’ (ALARP) can be adopted (G: Safe Work Australia).

It is additionally mentioned in several specific guidelines that nanomaterials might be toxic (S: CHS; DOE-NRSC; ISU). In a detailed view, an acute toxicity in the short run and a chronic toxicity in the long run has to be considered and a carcinogenity of particles cannot be excluded (S: DOE-NRSC).

One guideline specifically supports the precautionary measures if the mass of the nanomaterial sample exceeds the milligram range (S: TU Delft). The used nanomaterial shall be regarded as potentially toxic, if the primary units of the particles are smaller than 100 nm, if they are water insoluble and/or if the macroscopic material is classified as toxic (S: TU Delft). In this context, the expression ‘nanotoxic’ is used to underline the difference of this possible property to the potential toxicity specification of larger size particles of the same material. It is further mentioned that oxidizable materials in a condition, which they define as nanopowder state, must be considered as potentially pyrophoric and explosive when in contact with air (S: TU Delft).

The risks of reproductive toxicity (G: OSHA-EUROPA), sensitization (G: OSHA-EUROPA), pulmonary inflammation, granulomas and fibrosis (G: Hallock et al., 2009) are also addressed in general nanomaterial guidelines which are also applicable for laboratories.

[2] The specific aspects of the guidelines can be found in Annex II.

Additionally, it was recommended that the general precautionary measures for new substances with unknown hazardous properties should be also applied for unknown nanomaterials (L: AGS-BMAS; DGUV). New substances in laboratories, which are insufficiently examined for their properties, which includes acute and chronic toxicity and physico-chemical characteristics, shall be treated like not less than acute toxic, caustic, chronically toxic, flammable, pyrophoric and explosive (L: AGS-BMAS; DGUV).

2. Categorization[3]

Extending the precautionary approach to treat the nanomaterials as potentially toxic due to some of their unknown properties, a number of proposals to grade the potential hazard exist (S: AIST; EPFL; DOE-NRSC; Georgia Tech; HSE-a; NASA-ARC; ORC Worldwide; Penn-EHRS; TU Delft, UCI; UCSB).

One aspect of categorization distinguishes the various physical conditions of the used nanomaterials (S: DOE-NRSC; EPFL; Georgia Tech; HSE-a; NASA-ARC; ORC Worldwide; Penn-EHRS; TU Delft; UCI; UCSB). Manufacturing and handling procedures, that involve dry, dispersible nanoparticles, nanoparticle agglomerates or nanoparticle aggregates, require more stringent risk management controls than those where nanoparticles are suspended in liquids where their exposure is substantially reduced (S: DOE-NRSC). The exposure can be minimized further by handling solid nanomaterials with nanostructures fixed to the material surface, or moreover solid materials with imbedded nanostructures (S: DOE-NRSC).

In one specific nanomaterial guideline for laboratories, five handling categories for nanomaterials are differentiated (S: AIST). The handling category 1 is related to samples embedded in a matrix since no potential for nanomaterial release can be expected. Handling category 2 refers to work which is operated in an enclosed system, a sealed reactor or glove box (S: AIST). Nanomaterials suspended in liquids are categorized in handling category 3 (S: AIST). The handling categories 4 and 5 are directed to work in open environment, i.e. manufacturing, cleaning, transportation, pre-treatment for measurement and works which include unsealing of containers or packages (S: AIST). The categories 4 and 5 generally apply if a potential for nanomaterial release exists (S: AIST). Category 4 and 5 are distinguished concerning the quantity of nanomaterial, which is used in an experiment (S: AIST).

Factors, which can influence the risk of nanomaterials, are, amongst others, the number and mass of insoluble particles (S: HSE-a) as well as their size (S: Georgia Tech; TU Delft). One criterion of relevance for a possible exposure mitigation action threshold was referred to as a minimum amount of nanomaterial (S: TU Delft). Furthermore, a minimum amount of specifically 1 g insoluble carbon particles (S: NASA-ARC) and generally 1 g of a used nanomaterial quantity per experiment was mentioned as threshold criterion of relevance (S: AIST). This value was decided based on the evaluation result provided by the respective research institute (S: AIST)

Particles with a high surface reactivity were also considered to possess a higher toxicity risk (S: Georgia Tech).

Additional to the specific nanomaterial guidelines related to laboratory use, several recommendations are given by general nanomaterial guidelines also applicable to nanomaterials. Extending the correlation between size and toxicity potential, it is highlighted that certain small particles that are smaller than 10 nm reach the alveolar spaces in the lungs in case of inhalation and particles with a diameter of 1 µm or less are able to penetrate the human epidermis (G: Hallock et al., 2009).

[3] The specific aspects of the guidelines can be found in Annex III.

The issue of hazard assessment has a high complexity and the toxicological profile of nanomaterials is supposed to be based on their morphology, size, surface, solubility, agglomeration/ aggregation, mass, surface modifications, particle concentration and volume (G: IRSST; OSHA-EUROPA). The toxicity can be further influenced by crystalline structure and charge or even contaminants (G: IRSST; Schulte et al., 2008). Other factors with impact on toxicity can be the reactivity, redox potential, potential to generate free radicals, porosity, hydrophilicity/hydrophobicity, biopersistence, and the age of particles (G: IRSST). However, it was highlighted that it is currently still uncertain, which parameters represent the best predictive value for toxicity (OSHA-EUROPA). It was therefore suggested to elucidate, which of these properties represents the best predictive value for toxicity (G: OSHA-EUROPA). Another hazard assessment suggests, since it is not possible to test each particle type, to develop and validate strategies which involved testing to categorize nanoparticles by their possible toxicity (G: Schulte et al., 2008). Another guideline points out that this would facilitate development of new approaches like structure activity relationships or various end points of *in vitro* experiments, such as inflammatory markers or the generation of reactive oxygen species (ROS) (G: Schulte et al., 2008).

3. Risk Assessment[4]

Performing a risk assessment is generally supported by a high number of guidelines (S: DOE-NRSC; HSE-a; ORC Worldwide; UD; VCU). This risk assessment can be generated individually for all involved nanomaterials and processes (S: VCU). The requirements of scientific information, past experience and a regular review are regarded to be necessary for the reliability of the risk assessment (S: HSE-a). Even though the need of a risk assessment is generally accepted, the opinions of the essential contents are diverse.

It was mentioned that the risk assessment should both involve a well-defined description of the work, subject matter experts, hazards and uncertainties as well as specify hazard controls (S: DOE-NRSC). The applied hazard controls shall include engineered controls, design reviews, formal procedures, usage of PPE, training, other administrative controls and defined criteria for work-change control (S: DOE-NRSC).

From the risk assessment, the need for and the specific type of health monitoring shall be deduced (S: HSE-a). This includes an evaluation of the potential for worker exposure to nanomaterials (S: DOE-NRSC).

In the area of work process procedures, the use of electrical and magnetic fields or temperature gradients as well as the possible risk of fire and explosion should be noted (S: ORC Worldwide). It was furthermore mentioned that the waste stream collection and disposal of materials containing nanoparticles in solid, liquid or air is also an important issue.

They also suggest considering the specific properties of the nanomaterials, which include the physical form, the nanoparticle size range and the toxicity (S: ORC Worldwide).

In one general guideline related to nanomaterials, it is mentioned that in later development/production activities, and once the toxicological and other relevant properties of the nanomaterial have been determined, the control measures should be reviewed through a thorough process-specific risk assessment and, if warranted, modified accordingly (G: Safe Work Australia). The authors recommend that a complete life-cycle analysis of the nanomaterial should always be made to identify potential ‘hotspots’ of worker exposure, including construction, packaging, manufacturing, handling, maintenance or cleaning work, and end-of-life and safe disposal issues (G: Safe Work Australia). It is highlighted that a whole range of jobs

[4] The specific aspects of the guidelines can be found in Annex IV.

and tasks need to be considered (G: Safe Work Australia). Additionally, they recommend that existing ventilation systems that are effective for extracting ultrafine dusts in other industries should also be employed and optimally maintained where appropriate, in order to reduce exposure to engineered nanomaterials (G: Safe Work Australia).

The necessary information about the toxicity is specified further in several general guidelines related to nanomaterials. For the purpose of taking preventive measures against exposure, understanding the properties of nanomaterials is regarded as essential aspect (G: MHLW). One suggestion is a single case assessment according to the physico-chemical (G: IRSST; HMUELV; OSHA-EUROPA), toxicological and ecotoxicological properties (G: HMUELV). The knowledge on nanomaterial properties such as their particle size distribution, particle morphology, particle composition, particle surface area, particle number concentration, particle structure and reactivity in solution shall be used for the purpose of risk assessment (G: OSHA-EUROPA; Safe Work Australia). Also, it is pointed out that the presence of substances such as detergents, surfactants and other "surface active" chemicals are known to increase the absorption rate of some chemicals, which could include nanomaterials (G: Safe Work Australia).

The risk assessment shall be based on the most current toxicological data on the specific material as well as exposure assessments and exposure control information data (G: PENNSTATE).

These current data can be provided by the manufacturers of nanomaterials (G: MHLW) and gained for instance by web research (G: Hallock et al., 2009). One guideline suggests for the case of no or insufficient data available for risk assessment to perform risk estimation either from existing data or determined by the judgment of experts (G: Safe Work Australia).

It is recommended that the efficiency of the preventive measures against exposure shall be confirmed by measurement of the concentration of nanomaterials (G: MHLW). Furthermore, it is stated that this measurement should be performed not only at regular intervals, but also at the time, when the status of nanomaterial-related work changes (G: MHLW). Suggestions for measurement instruments are SMPS (Scanning Mobility Particle Sizer), CPC (Condensation Particle Counter) and DC (Diffusion Charger-based Surface-Area Monitor) etc. (G: MHLW).

In one guideline, the regular repetition and enhancements of the risk analysis is recommended in order to account for new scientific knowledge and practical conditions of the work environment (G: IRSST). Here, a case by case approach shall be preferred (G: IRSST). This guideline also suggests to apply a control banding approach for a qualitative risk assessment, which is based on the use of a limited number of factors for evaluating the risk level in order to reduce the complexibility and increase the applicability for non-experts (G: IRSST).

A control banding approach for research and early development activities involving nanomaterials is furthermore suggested in another general guideline, where similar control measures shall be used within categories of nanomaterials that have been grouped ("banded") according to their exposure potential and hazardous properties (G: Safe Work Australia). In this guideline, control banding is considered to be an appropriate method because of the current lack of data available for the risk assessment of individual nanomaterials, since there is some understanding of hazards posed by different groups of nanomaterials (G: Safe Work Australia).

For instance, if nanomaterials are classified as potential carcinogens on the macroscale, then specialist advice is recommended when handling these nanomaterials (G: Safe Work Australia).

It is regarded as an essential aspect that the risk assessment is in accordance with the existing regulations for individual settings and materials and does not have its own separate requirements (G: Safe Work Australia).

4. Physical Hazards[5]

In several specific nanomaterial guidelines for laboratories, physical hazards like catalytic effects, fire or explosion, which apply especially to nanopowders and nanofibers, are mentioned (S: AIST; DOE-NRSC; Georgia Tech; HSE-a; ISU; MIT; TU Delft; UC). It is also elucidated that nanoparticles might be pyrophoric (S: TU Delft).

Supplementary, in one general nanomaterial guideline applicable for laboratories, it is highlighted that, depending on the specific production methods being used, other hazards should be considered such as electrocution associated with the generation of a plasma via the use of high currents or asphyxiation hazards owing to possible leaks of inert protective gases during some processes (G: OSHA-EUROPA). In another guideline, it is mentioned that the ignition energy and the violence of an explosion are influenced by the particle size or area (G: IRSST).

Regarding the handling of new substances with unknown hazardous properties in laboratories, it is highlighted by a general laboratory guideline, which is also applicable to nanomaterials, that new substances shall be treated with high precaution since these new substances are insufficiently examined especially concerning their acute and chronic toxicity and physico-chemical characteristics (L: AGS-BMAS; DGUV). Hence, it is stated that they could be acute toxic, caustic, chronically toxic, flammable, pyrophoric and explosive (L: AGS-BMAS; DGUV). It is further specified that nanomaterials with insufficiently known properties shall be treated like such new substances (L: DGUV).

5. Safer Manufacturing Approaches[6]

Safer manufacturing approaches are generally recommended by several reports regarding the handling of nanomaterials in laboratory scale (S: HSE-a; ORC Worldwide; UCI; UCSB; UD).

It is stated that a potential form of safer manufacturing approaches is a change of the physical condition of the used nanomaterial, i.e. replacing the powdered state by a liquid or macroscopic solid state in order to minimize the possible release of nanoparticles (S: CHS; DOE-NRSC; ORC Worldwide; UCI; UCSB; UD). Specifically it is suggested to consider applying wet method which treats nanomaterials as suspension liquids as an effective measure to prevent exposure (S: AIST). Furthermore, it is highlighted that the risk of exposure to the liquid dispersion itself and chemical reactions should always be kept in mind (S: AIST).

Several general reports related to nanomaterials state that hazardous substances shall be replaced with less hazardous substances in this risk mitigation approach if this is technically feasible and economically acceptable (G: HMUELV; Hoyt and Mason, 2008; IRSST; OSHA-EUROPA).

However, this principle does not specifically relate to nanomaterials since the properties of nanomaterials are not obligatory associated with a hazard assumption, but result in the application of the

[5] The specific aspects of the guidelines can be found in Annex V.

[6] The specific aspects of the guidelines can be found in Annex VI.

precautionary approach. Since the properties of the respective nanomaterial might be especially required, the safer manufacturing approaches apply preferably to the form of appearance of the respective nanomaterial.

Two general nanomaterial guidelines mention explicitly that a substitution of nanomaterials might not be a suitable hazard reduction method since the presupposed unique properties of nanomaterials include their production and use (G: NanoSafe Australia; Safe Work Australia).

However, the option to reduce the *in vitro* cytotoxicity of several nanomaterials, e.g. of fullerenes, carbon nanotubes, quantum dots and metal/metal oxides by modifications is pointed out (G: Safe Work Australia).

It is also suggested to modify the type of process, for example to replace a dry process with a wet process (G: IRSST). The handling of bound nanomaterials in dispersions, pastes, compounds or solid media is for instance favored over powder nanomaterials to minimize possible exposure (G: BAuA / VCI; HMUELV; Safe Work Australia).

A further guideline recommends measures of preventing fire and explosion depending on the property of the nanomaterials, for instance the reduction of dust concentration, prevention of static electricity generation and the reduction of oxygen concentration in manufacturing/handling experiments (G: MHLW).

6. Technical Measures[7]

The need for technical exposure mitigation has been accentuated by all specific nanomaterial guidelines which are related to laboratories (S: CHS; DOE-NRSC; EPFL; Georgia Tech; HSE-a; ISU; MIT; NASA-ARC; NSF; ORC Worldwide; OUHSC-IBC; Penn-EHRS; TU Delft; UBC; UC; UCI; UCSB; UD; VCU). Specifically it was recommended that procedures involving the handling of nanomaterials shall be performed in a closed system (S: AIST; DOE-NRSC; MIT; NASA-ARC; ORC Worldwide; TU Delft). A closed system is specifically required for activities like measuring raw or manufactured materials, pouring (including mixing) into or collecting from the producing or processing equipment, cleaning the container, waste processing etc., unless there is no potential for exposure (S: AIST).

A ventilation and filtration of this enclosure is recommended especially if free or low level aggregated/agglomerated nanoparticles are handled (S: Penn-EHRS), but also for suspensions of nanoparticles or the cleaning of potentially contaminated parts of reactors or furnaces (S: MIT). It is further recommended that the enclosure shall feature a negative pressure differential compared to the worker's breathing zone (S: DOE-NRSC).

One example for a closed system is a fume hood or fume cupboard, respectively (S: CHS; ISU; MIT; NASA-ARC; Penn-EHRS; UCI; UCSB). It is mentioned that the exhaust air has to be passed through a HEPA filter, since at this time it is the only air pollution control device known to control nanoparticles with high efficiency (S: CHS). According to several specific nanomaterial guidelines relating to laboratories, a fume exhaust hood (S: Georgia Tech; NASA-ARC; TU-Delft; UC; UCI; UCSB) or ventilated hood with air flux (S: EPFL) is required especially to expel free of low level aggregated/agglomerated nanoparticles from tube furnaces or chemical reaction vessels.

[7] The specific aspects of the guidelines can be found in Annex VII.

It is recommended that, independently on the type of hood, the effectiveness of the air flow shall be tested before using it (S: ORC Worldwide). A nanoscale particle counter is suggested to determine if free or low level aggregated/agglomerated nanoparticles escape from the containment (S: ORC Worldwide).

In one general nanomaterial guideline, which can also be applicable for nanomaterials and relates to carbon nanotubes, it is mentioned that a good visualisation of the air flow can be provided by smoke tubes (G: Hoyt and Mason, 2008). This could help to detect leaks and find the optimal application of hoods, etc. for exposure mitigation.

It is distinguished in a general nanomaterial guideline, which can likewise be applied for laboratories, that working with nanomaterials shall either be performed under an ducted fume cupboard or a recirculating fume cupboard (G: HSE-b). In this case, the ducted and the recirculating fumehood shall be in accordance to BS 7989:2001 and BS EN 14175-4:2003 including HEPA filtration, respectively (G: HSE-b).

A further possibility for a closed system is a biological safety cabinet (S: CHS; DOE-NRSC; ISU; MIT; Penn-EHRS; OUHSC-IBC). Examples include class II (S: CHS; DOE-NRSC; MIT) cabinets type A2 (S: MIT), B1 (S: CHS; MIT) or B2 (S: CHS; MIT). It is mentioned that, since type A2 and B1 cabinets are only equipped by recirculation of air, processes involving higher amounts of dust shall be avoided as the internal fans of these cabinets are not explosion proof (S: MIT). For processes including higher amounts of free or low level aggregated/agglomerated nanoparticles and solvents, B2 cabinets with 100 % exhaustion are regarded as appropriate to avoid recirculation of nanoparticles and solvents into the room (S: MIT). Air from inside the cabinet shall not be recirculated within the laboratory except as provided for in ANSI Z9.7 (American National Standard for Recirculation of Air from Industrial Process Exhaust Systems) (S: DOE-NRSC).

The requirements for certification are explained in detail in a general nanomaterial guideline which can also be applied for laboratories. In this guideline, a certification by NATA (Australian National Association of Testing Authorities) and an annual testing of the efficiency are suggested (G: NanoSafe Australia).

The advantage of a laminar flow system in a cabinet has also been mentioned in specific nanomaterial guidelines related for laboratories (S: CHS; Georgia Tech; ORC Worldwide; TU Delft; UBC; UC). According to one guideline, the laminar flow hood, which has preferably low velocity such as the models provided by Flow Sciences (S: ORC Worldwide), shall be equipped with HEPA filtration (S: Georgia Tech; TU Delft, UBC; UC). In one guideline, it is specifically advised against horizontal laminar flow hoods, which direct a flow of HEPA-filtered air into the face of the operator, in case of free or low level aggregated/agglomerated nanoparticle handling (S: DOE-NRSC).

This opinion is shared by a general nanomaterial guideline, which can also be applied for laboratory scale, which does not recommend the usage of laminar flow cabinets, since they blow contaminated air towards the operator (G: NanoSafe Australia).

In one specific nanomaterial guideline related to laboratories, advice is given against handling engineered nanoparticles under a downflow booth, since the protection without additional respiratory protection is considered as not sufficient (S: ORC Worldwide).

Glove boxes (S: AIST; CHS; DOE-NRSC; ISU; MIT; ORC Worldwide; Penn-EHRS; TU Delft; UCI; UCSB) and glove bags (S: AIST; DOE-NRSC; MIT) have been likewise suggested as examples for a closed system. Processes where engineered nanoparticles are produced shall be generally conducted in glove boxes or bags with negative pressure differential compared to the workers breathing zone (S: DOE-NRSC). In one guideline, it is highlighted that the air reactivity of precursor materials may make it unsafe to operate in a negative pressure glove box and a positive pressure differential may be needed, which shall be assured with a helium leak test (S: DOE-NRSC).

It is recommended that reactors and furnaces, which are required for nanoparticle processing, are equipped with ventilation (S: MIT). Gasses should be run through a liquid bubbler system, if possible (S: MIT).

A general report regarding nanomaterials, which can also be applied for laboratories, highlights the university best practice in using reactors and furnaces in order to prevent inhalation exposure (G: Hallock et al., 2009). With regards to synthesis processes in reactors or furnaces, the exhaustion of reactor gases, the purging before opening, the providing local exhaust ventilation for emission points and the performing of part maintenance in fume hood are regarded as essential aspects which increase the safety level (G: Hallock et al., 2009).

The exposure can be decreased with local exhaust ventilation (LEV) (S: AIST; CHS; DOE-NRSC; HSE-a; MIT; NASA-ARC; ORC Worldwide; UCI; UCSB; UD). A LEV is recommended if the work processes make enclosure difficult (S: AIST). This LEV can be HEPA-filtered (S: UD) and associated with a reactor (S: NASA-ARC). It is stated that the LEV shall include a push-pull ventilation system (S: AIST). The use of an electric dust collector, etc. is regarded as reasonable if the targeted material can be collected properly (S: AIST). Another guideline suggests using additional respiratory protection and close localisation to the nanoparticle source if the LEV is open (S: ORC Worldwide). LEV can be applied for instance to clean parts of reactors or furnaces that are too large for a fume hood (S: MIT). In this case, a design of a special customised enclosure, which is evaluated by a health and safety office, can be reasonable (S: MIT). For handling of fumes and gases, a dedicated exhaust duct is suitable (S: ISU). It is suggested to periodically inspect the LEV to ensure the proper operation (S: AIST).

One general nanomaterial guideline, which is applicable to research in laboratory scale, highlights that moreover access opening for maintenance and inspection of enclosures shall be equipped by LEV (G: MHLW). In this guideline, it is suggested to direct the outlet of the LEV directly open to the outside air or, if this would be difficult to achieve, to connect the LEV to the existing exhaust duct (G: MHLW). It is further proposed to select high performance filters, which are capable of collecting nanomaterials like HEPA-filters (G: MHLW).

Regular maintenance and annual testing of local exhaust ventilation are recommended by two general nanomaterial guidelines (G: HSE-b; MHLW).

A ventilation system in the working area, where nanomaterials are handled, is proposed by a number of specific nanomaterial guidelines for laboratories (S: CHS; DOE-NRSC; MIT; NASA-ARC; Penn-EHRS; TU Delft, UC; UCSB; UD). It is recommended that, considering the laboratory airflow, arrangement and separation of the equipment shall be carefully laid out corresponding to the level of exposure (S: AIST). The airflow control is regarded as an effective measure to prevent exposure because nanomaterials and their quantities are very small and their behaviour is similar to that of airflow (S: AIST). It is also mentioned that a stable lower air pressure equivalent to 6 mm water column shall be maintained in the laboratory area, where nanoparticles are handled (S: EPFL). Furthermore, the proposal is made to install a non-recirculating ventilation system with 6 to 12 air changes per hour and negative laboratory pressurization (S: Penn-EHRS). HEPA-filtration is recommended for passing the exhaust air (S: CHS).

The issue of ventilation is also addressed by some general nanomaterial guidelines, which can also be applied for laboratory scale. A regular maintenance and function testing is considered as mandatory (G: BAuA / VCI). According to EN 1822-1 to EN 1822-5, multistage filters with a HEPA- or ULPA-filter as final filter are regarded as reasonable (G: IRSST; OSHA-EUROPA; Safe Work Australia). Another mentioned extraction method for particles involves the use of electrostatic precipitation, which can remove nanoparticles (G: Safe Work Australia).

Further safety equipment like eyewash station according to ANSI and OSHA requirements (S: VCU), safety shower, first aid kit, fire extinguisher and emergency exits are mandatory in the laboratory area (S: UBC).

7. Organizational Measures[8]

The need for organizational measures is emphasized in a number of specific nanomaterial guidelines applicable for laboratories (S: CHS; DOE-NRSC; EPFL; Georgia Tech; HSE-a; NASA-ARC; ORC Worldwide; OUHSC-IBC; Penn-EHRS; TU Delft; UBC; UC; UCI; UCSB; UD).

The accountability for surveillance shall be placed at either a responsible person like a project manager (S: EPFL), a cleanroom manager (S: UBC), a security agent (S: EPFL) or a health and safety officer (S: CHS; Georgia Tech; ORC Worldwide; VCU).

One prominent organizational aspect refers to the access control to the working area (S: AIST; EPFL; UBC; UD). Possibilities to control the access can be a login (S: UBC), a control access zone (S: EPFL) and a user list at the entrance (S: EPFL; UBC). The signage “dangerous nanoparticles” prevents the unintentionally admittance of unauthorized persons (S: EPFL).

It is recommended that working outside the normal working hours should be avoided (S: UBC). A dangerous work shall be than only performed from two persons together (S: UBC), whereas it is sufficient for less-dangerous works if an informed person is present in the building (S: UBC). The cleanroom area, where nanoscaled particles are handled, may be closed at nights (S: UBC).

A general guideline for nanomaterials considers reducing the time spent in possible exposure areas (e.g. hot areas) and the number of potentially exposed personnel (G: Safe Work Australia).

It is also suggested by one specific guideline for nanomaterials in laboratories to separate the areas, where nanomaterial exposure can occur, from other areas (S: AIST). Firstly, it is recommended to separate the office from the laboratory area. Secondly, the laboratory shall be divided into the areas with potential for exposure and the areas not susceptible to exposure (S: AIST).

Special areas further recommended are facilities for changing clothes (S: CHS; DOE-NRSC; EPFL; UBC; UD) or, as mentioned in a single report, showering (S: UD). Also hand-washing facilities could be required (S: OUHSC-IBC; Penn-EHRS). Furthermore, an area, in which work clothing and protective wears/equipment can be stored, and a changing room are regarded as necessary (S: AIST). Nanomaterial adhered work clothing shall be treated appropriately to prevent the nanomaterials from spreading beyond the workplace (S: AIST). For this reason, it is suggested to separate work clothing together from other clothing by using separate lockers (S: AIST). A hand-wash and eye-wash station near the changing room shall be additionally installed (S: AIST). Furthermore, it is recommended to organize the installation and fixtures on the floor and wall in a way to facilitate cleaning up, for instance by water rinsing or vacuum cleaning of the floor (S: AIST).

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[8] The specific aspects of the guidelines can be found in Annex VIII.

In one general guideline, the installation of locker rooms to avoid mixing work and street clothes is likewise recommended (G: IRSST). Supplementary, it is suggested that a laundry service should be provided to the employees, so that they do not take clothing contaminated with nanomaterials to their home (G: NanoSafe Australia).

To promote good personal hygiene, washbasins and showers shall be installed to allow decontamination of workers (G: IRSST). Another general aspect on organization refers to the standardization of all work surfaces, which should be non-porous and easy to clean (G: IRSST).

A number of specific nanomaterial guidelines related to laboratories suggest minimizing the release of dust by mitigation of the exposure (S: CHS; DOE-NRSC; EPFL; Georgia Tech; HSE-a; TU Delft; VCU). Since the risk potential of possible fire and particle dust explosion increases due to the combustible particulate being nanosize, preventive measures shall be implemented, for example usage of explosion proved equipment in case of handling combustible gas or solution (S: AIST). The preparation of nanoparticles with minimal exposure can be ensured by the compliance with standard operating procedures (S: VCU) and the measurement of emissions to the air (S: DOE-NRSC).

One general nanomaterial guideline suggests the preparation of operation rules on working nanomaterials to the workers (G: MHLW). They specify that these operation rules shall contain information about the health effects of the nanomaterials regarding the working environment (G: MHLW). A general nanomaterial guideline proposes to generally minimize the time of exposure by organizing the timeline of working procedures (G: HMUELV).

Several specific nanomaterial guidelines for laboratories state that activities such as eating, drinking, chewing gum or smoking as well as the storage of food or cosmetic products shall be prohibited in the working area (S: EPFL; NASA-ARC; UBC; UC; UCI; UCSB; UD). Pipetting with the mouth is likewise not permitted (S: EPFL). According to these aspects, the storage of nanoparticles in non-working areas like offices or the hallway is not allowed (S: EPFL). An example for the correct storage of nanoparticles describes the storage of carbon nanopowder amount of more than 1 g in sealed metal containers (S: NASA-ARC). These metal containers are in this case recommended in order to avoid the generation of electrostatic activity (S: NASA-ARC).

In one guideline, it is suggested to enhance the safety in the laboratories, where nanoparticles are handled as well as in the entrance room, by fitting the working zone with a stable air depression (6 mm of water column) (S: EPFL). It is recommended to equip the cleanroom with a telephone for the case of emergency (S: UBC). A single guidance suggests that the air is monitored with a nanoparticle detector and if the quantity of nanoparticulate materials produced during gas phase work exceeds the limit of 1 µg/h (S: TU Delft). For this purpose, the instruments “Joint Length Monitor” and “DelfChemTech” are emphasized (S: TU Delft). One indirect opportunity to both determine the exposure of the workers and document the performed activities is by recording the equipment time usage (S: UBC).

An exceptional impact affects the usage of needles and syringes (S: OUHSC-IBC). It is highlighted that a safe needle device for administration and a needle-locking for disposable syringes are required in this case (S: OUHSC-IBC).

7.1 Labelling[9]

It cannot be assumed that nanomaterials are all hazardous, but the precautionary approach may be applied. For this reason, labelling is required regarding the in-company handling of nanomaterials, which is described as following in the individual guidelines.

Safety and health signs and texts to inform occupational safety and health measures for nanomaterials such as appropriate hazard and exposure mitigation signs areis regarded as necessary in several specific nanomaterial guidelines, which are related to nanomaterials and address this point (S: CHS; DOE-NRSC; MIT). Several suggestions for required labels have been reported.

It is recommended that areas, where easily dispersible nanomaterials are used, should be labelled with appropriate signs (S: DOE-NRSC; MIT). It is specified that these post signs should indicate the hazards, PPE requirements, and administrative control requirements (S: DOE-NRSC; MIT). Furthermore, it is mentioned that these signs should be placed at entry points into designated areas, where dispersible, engineered nanomaterials are handled (S: DOE-NRSC). A designated area may be an entire laboratory, an area of a laboratory or a containment device such as a laboratory hood or glove box (S: DOE-NRSC). It is mentioned that a "Designated Area" sign, which could be available from the EHS office, could be used, if indicated, to label the fume hood, laboratory bench, or laboratory itself (S: MIT). Equipment, which could be contaminated by nanoparticles can be separately labelled. For instance, one guideline recommends labelling HEPA vacuum cleaner with the sign “For Use with Nanoparticles Only” (S: CHS).

In one guideline, the following labelling for containers containing nanomaterials is suggested: CAUTION - Nanomaterials Sample - Consisting of (technical description here) Contact: (POC) at (contact number) in Case of Container Breakage (S: CHS). However, details about the context are missing, i. e. it is not specified if these containers shall be dedicated for storage, transport or waste management.

However, other guidelines address this issue in more details. It is suggested that nanomaterial storage containers should be labelled for their contents in engineered nanomaterial (S: MIT) respectively nanoparticulate form (S: DOE-NRSC), such as "nanoscale zinc oxide particles" or other identifier instead of just "zinc oxide" (S: MIT).

One guideline recommends to internally transport nanomaterials in closed, labelled containers, e.g. marked "Zip-Lock" bags between work stations (S: CHS; DOE-NRSC). They suggest for nanomaterials, which are being moved outside, that the label text shall indicate that the particulates might be unusually reactive and vary in toxic potential, quantitatively and qualitatively, from normal size forms of the same material (S: DOE-NRSC). Additionally, they make the statement that for external transport: nanomaterials with suspected or recognized hazardous properties (toxic, reactive flammable) must be packaged, marked, labelled and shipped in accordance with 49 CFR 100 to 185 and applicable DOE Orders with an accompanying properly prepared dangerous goods declaration and in accordance with the ICAO technical instructions (S: DOE-NRSC). Furthermore, they highlight that nanomaterials with unknown hazardous properties still may pose health and safety issues and that they shall therefore be consistently packaged and labelled using the equivalent of a DOT-certified Packing Group I (PG I) container (S: DOE-NRSC). For transport, the following explanatory notes are suggested: CAUTION - Nanomaterials Sample - Consisting of (technical description here) Contact: (POC) at (contact number) in Case of Container Breakage (S: DOE-NRSC).

Regarding waste management, labelling the waste container with a description of the waste and the words "contains nanomaterials" is recommended (S: DOE-NRSC; MIT). Available information

[9] The specific aspects of the guidelines can be found in Annex VIII.1.

characterizing known and suspected properties shall also be included (S: DOE-NRSC). Another suggestion refers to the addition of a hazardous red tag (S: MIT).

According to a general guideline for nanomaterials, necessary information to facilitate preventive exposure measure is the name and components of nanomaterials and precautions for handling such nanomaterials on the labelling of the container or package (G: MHLW). Supplementary, it is mentioned in general nanomaterial guidelines also related to laboratories that the consistency of the signs indicating hazards and exposure mitigation requirements on all containers containing nanomaterials with the laboratory requirements is a precondition (G: PENNSTATE).

It is also highlighted that a substance can have in principle different categorization and labelling depending on the specific properties and that the properties of a nanomaterial, which deviate from the bulk material, can be reflected by categorization and labelling (G: OSHA-EUROPA).

7.2 Personal Training[10]

One important point of organisational measures addresses a broad range of possibilities for information and training of the workers who are potentially exposed to nanomaterials (S: AIST; CHS; DOE-NRSC; EPFL; HSE-a; NASA-ARC; NSF; UBC; UCI; UCSB; UD; VCU). It is suggested to brief workers handling nanomaterials on the potential hazards of the research activity followed by a written report for the participants (S: UCI; UCSB). In some guidelines, a regular information (S: UD) or annual training (S: CHS) is suggested.

Several other reports explain the proposed training courses in more detail. In one guideline, regular workers attend to several courses such as a chemical and laboratory safety orientation course and a qualification course on individual equipment (S: UBC). Regarding access rules, it is mentioned that students need to be additionally chaperoned by a qualified user, whereas visitors need supplementary agreement with the cleanroom manager to access the nanomaterial working area (S: UBC).

It is also recommended that the training of the employees shall be performed in collaboration with the project managers (S: EPFL). It is further regarded to be reasonable to involve the employees in the design and implementation of control measures (S: HSE-a).

In one guideline, it is highlighted that training courses shall cover recommendations for using personal protective equipment, handling potentially contaminated clothes or surfaces and disposal of spilled nanomaterials (S: DOE-NRSC). In another guideline, the importance of the education about the potential risks associated with the handlings of nanomaterials is highlighted (S: AIST).

The workers knowledge on the used nanomaterials can be expanded further by a provided lab safety plan, standard operating procedures (SOP), material safety data sheets (MSDS) and Job Hazard Analysis Worksheets (JHA) (S: NASA-ARC). It is furthermore mentioned that the education of the workers shall be based on an established manual for the handling procedures (S: AIST).

Also, specific training courses regarding specific nanoparticle-related health and safety risks, laboratory safety training modules, special instructions for injections and needles and a respiratory protection program according to OSHA's 29 CFR 1910.134 and ANSI Z88.2 requirements are noted (S: VCU).

[10] The specific aspects of the guidelines can be found in Annex VIII.2.

Beside the specific nanomaterial guidelines related to laboratories, the topic of personal training is mentioned in some general nanomaterial guidelines. A training and information of the employees on controlling the exposure to nanomaterials is recommended (G: HSE-b). The instructions of the chemical hygiene plan are regarded as generally applicable (G: Hallock et al., 2009). One general guideline for nanomaterials lists that the employees shall be educated on operation rules, physical and chemical properties of nanomaterials, health effects of nanomaterials, control measures for the work environment, preventive measures against exposure to nanomaterials such as the use of PPE and measures of preventing fire and explosion (G: MHLW). Especially for respiratory protection, the employees shall be instructed in detail about the following aspects of respiratory protection: 1) proper selection; 2) the method about pulling on; 3) measurement method of leakage test; 5) method of fit test and 6) storage and maintenance (G: MHLW).

7.3 Cleaning[11]

The aspect of cleaning is an essential issue mentioned in the predominant number of specific nanomaterial guidelines for laboratories (S: CHS; DOE-NRSC; EPFL; Georgia Tech; ISU; MIT; NASA-ARC; ORC Worldwide; OUHSC-IBC; Penn-EHRS; TU Delft; UBC; UC; UCI; UCSB; UD; VCU). The cleaning shall be organised by the person in charge of cleaning in the laboratory (S: EPFL).

How frequently the cleaning ought to be carried out, is differently regarded spanning a range from cleaning after each procedure (S: VCU), cleaning at the end of each shift (S: DOE-NRSC; UD), after a daily (S: CHS; EPFL; Penn-EHRS; UCI) or a weekly period (S: NASA-ARC).

It is recommended that the routine cleaning of potentially contaminated surfaces shall be performed either by using a HEPA filtered vacuum cleaner (S: AIST; CHS; DOE-NRSC; ISU; NASA-ARC; Penn-EHRS; TU Delft; UC; UCSB; UD), which is labelled “for use with nanomaterials only” (S: CHS), or by wet wiping (S: AIST; CHS; DOE-NRSC; ISU; NASA-ARC; OUHSC-IBC; Penn-EHRS; UBC; UCI; UCSB; UD).

The wet-wiping method can be accomplished using cleanroom or disposable wipes (S: DOE-NRSC; UBC) and spraybottles (S: NASA-ARC). Recommended agents taken for wet-wiping are iso-propanol (S: UBC), water (S: NASA-ARC) or cleaning agents compatible with the respective nanomaterial (S: ISU; OUHSC-IBC; Penn-EHRS). Possible complications due to chemical or physical properties of the agent ought to be considered (S: DOE-NRSC).

The application of solvents is regarded controversially since in one guidelines it is recommended to utilise them to clean lab equipment and exhaust systems (S: NASA-ARC), but another guideline advises against their use (S: ISU). Both guidelines provide no detailed reasons for their argumentation.

If HEPA-filtered vacuuming is carried out, the potential air-reactivity of nanoscaled powders shall be considered (S: DOE-NRSC). In accordance, several guidelines explicitly prohibit dry sweeping, the usage of compressed air (S: CHS; DOE-NRSC; NASA-ARC) respectively air spray (S: AIST) or vacuuming without HEPA filters (S: NASA-ARC). A single guideline addresses the importance of a half-face respirator with P100 filter during vacuuming (S: ISU).

A benchtop protective material (S: CHS; UCI; VCU) can likewise be chosen instead of vacuuming. This bench paper shall contain impervious backing to limit the potential for contamination of surfaces (S: VCU). Both recommendations for cleaning daily (S: CHS) or after each usage (S: VCU) exist.

[11] The specific aspects of the guidelines can be found in Annex VIII.3.

It is highlighted in one guideline that water sensitive instrument surfaces shall be cleaned with electrostatic microfiber cleaning cloths (S: NASA-ARC).

A walk-off adhesive mat at the entry of the working area is assumed to minimize the spread of nanoscaled particles (S: DOE-NRSC; UBC; UCSB).

Regarding the wet wiping method, one general nanomaterial guideline remarks that the water-solubility of the nanopowder has to be taken into account regarding the wet wiping method (G: MHLW). For this reason, cleaning operations shall be conducted in consideration of both the status of the workplace and the properties of nanomaterials (G: MHLW).

Special requirements for the vacuum cleaner are mentioned in one general nanomaterial guideline, which is also applicable for laboratory use (G: NanoSafe Australia). Quality features are fulfilled if the vacuum cleaner complies with the Australian standards AS 3544-1988 and its HEPA filter with AS 4260-1997 (G: NanoSafe Australia). According to these quality characteristics, an industrial vacuum cleaner for particulates hazardous to health, i. e. not a household vacuum cleaner, is required (G: NanoSafe Australia). The need for explosion-proof cleaning equipment is highlighted in the case of explosive nanoparticles (G: IRSST). This vacuum cleaner can be designed with insulating materials, a ground or an explosion vent to prevent production of ignition sources, i.e. sparks or static electricity. Another option is to use an electrical mobile vacuum cleaning system with an induction motor to avoid sparks (G: IRSST).

In cases of spills, several specific nanomaterial guidelines for laboratories likewise recommend wet wiping (S: DOE-NRSC; TU Delft; UCI; UCSB), vacuuming with a HEPA-filtered vacuum cleaner (S: DOE-NRSC; Georgia Tech; Penn-EHRS; TU Delft; UC; UCI; UCSB) and walk-off mats (S: DOE-NRSC; UCI; UCSB). Absorbent materials or liquid traps can also be applied (S: TU Delft).

Potential pyrophoric hazards that are associated with vacuuming nanomaterials shall be considered (S: DOE-NRSC).

Dry sweeping (S: DOE-NRSC; Penn-EHRS; UCI; UCSB) and the use of compressed air shall be prohibited (S: DOE-NRSC).

One guideline states that extra cautious preventive measures against exposure should be taken since the potential risk for exposure is increased (S: AIST).

It is mentioned that personal protective equipment may be required to avoid contact with nanoparticles and nanoparticle-containing solutions (S: TU Delft). This includes double nitrile gloves and, in the case of particle powder, respiratory protection (S: UCI; UCSB). It is highlighted that potentially contaminated clothes and personal protective equipment shall be cleaned carefully and thoroughly according to laboratory procedures in order to avoid secondary contamination (S: AIST; DOE-NRSC). The cleaning procedures and the referred type of nanoparticles are not further specified in this context.

It is recommended to wet wipe the affected area three times with soap and water or an appropriative cleaning agent (S: VCU). Barriers that minimize the air currents might be required if a liquid contamination occurs (S: CHS).

All exposed reaction vessels shall be cleaned in a fume hood (S: MIT; TU Delft) or other type of exhausted enclosure (S: MIT) using wet wiping or HEPA-filtered vacuuming. Equipment, which is too large to be enclosed in a fume hood, has to be cleaned using specially designed local exhaust ventilation (S: MIT).

In case of nanoparticle overflow, it is recommended to close and decontaminate the contaminated zone (S: EPFL). It is mentioned that in this case, the project manager shall give instruction to the work place about the procedure to follow in case of accident or incident (S: EPFL). For this purpose, it is highlighted that it could also be necessary to demarcate this zone with barricade tape (S: CHS) and contact the health and safety office (S: CHS; Georgia Tech).

It is mentioned especially for carbon-based nanomaterials, a spill kit containing spray bottles with water and disposable wipes could be reasonable (S: NASA-ARC).

A nanomaterial spill kit, which consists of barricade tape (S: CHS; MIT), latex (S: CHS) or nitrile gloves (S: CHS; MIT), disposable N95 (S: CHS) or P100 (S: MIT) respirators, absorbent material (S: CHS; MIT), wipes (S: CHS; MIT), sealable plastic bags (S: CHS; MIT) and a walk-off mat (S: CHS; MIT), could assure that appropriate equipment is present in case of contamination.

Beside these general opinions reflecting a mixture of differently stringent measures, several guidelines differentiate the way of spill handling according to the contamination amount.

Small spills can be cleaned by trained personnel (S: CHS). Small spills of powder, for instance less than 5 mg (S: VCU), can be firstly sprayed with a water mist (S: NASA-ARC) and wiped clean (S: NASA-ARC) or wiped with a wet cloth (S: CHS; MIT; ORC Worldwide) or paper towel (S: ORC Worldwide) dampened in soaped water (S: VCU). Small spills of solution, for instance less than 5 ml (S: VCU), shall be cleaned with absorbent material (S: NASA-ARC; MIT; VCU) with cleaning cloths or paper towels (S: NASA-ARC). The solutions ought to be cleaned immediately before they dry (S: NASA-ARC).

A number of recommendations exist for larger spills. A single guideline defines these spills as spills where the cleaning will take more than 5 min (S: NASA-ARC). An exact definition is missing in the other available guidelines. A possibility is cleaning these spills with a HEPA-filtered vacuum cleaner (S: MIT; ORC Worldwide) followed by wet wiping of the surface (S: ORC Worldwide). It might be also necessary to demarcate the area with barricade tape (S: DOE-NRSC) and contact the health and safety office (S: CHS; Georgia Tech; UCSB; VCU). Further options are to either leave the area or use personal protective equipment (PPE), i.e. a respirator and disposable protective clothing, and comply with the requirements for emergency response by hazardous materials user (S: NASA-ARC). A restriction of the laboratory entry to a laboratory waste management crew is also thinkable (S: DOE-NRSC).

Suggestions of the guideline documents referring to the treatment of contaminated materials are addressed in section 3.11 “Waste disposal”.

Similarly, it is suggested to call an emergency telephone number and restrict the entrance to the affected area to a designated hazardous material emergency response team if the spill exceeds the capability of the laboratory (S: NASA-ARC).

In general nanomaterial guidelines, which are also applicable for laboratories, special aspects of cleaning spills are highlighted further. An appropriate absorbent material is required for the wet wiping method (G: Hallock et al., 2009; Surrey-ATI). A previous collection of bulk material could be necessary in cases of larger spills (G: PENNSTATE). An essential issue is related to HEPA-filtered vacuum cleaners, which have to avoid electrostatic charges by neutralising any charges (G: Surrey-ATI).

Beside the various aspects of regular cleaning and cleaning of contaminations, the cleaning hygiene of the employees is an essential issue, which ensures a certain hygiene standard and consequently the safety of the employees.

The required hygiene can be achieved amongst others by washing hands before any procedure (S: EPFL) and after handling nanomaterials (S: ISU; MIT; Penn-EHRS), respectively before (S: VCU) and after (S: DOE-NRSC; VCU) wearing gloves. Hand washing shall also be performed before eating (S: UD), smoking (S: UD) or leaving the working area (S: Georgia Tech; UD). Soap and water can be sufficient to clean the hands (S: VCU). It might be necessary to include cleaning of the forearms (S: DOE-NRSC; MIT) depending on the area of contamination.

The working clothes shall be stored separately (S: UBC), whereas the laboratory coats shall be changed once in a work week (S: UBC).

Contaminated clothes are recommended to be changed promptly (S: VCU) with adjacent laundry (S: ISU) or to be disposed (S: DOE-NRSC; ISU). It could furthermore be necessary to wear disposable coveralls and boots if a certain probability for contamination exists (S: ISU).

8. Personal Protective Equipment[12]

The general application of appropriate personal protective equipment (PPE) while handling nanomaterials, which supplements organizational and engineering measures, is recommended by a number of guidelines (S: AIST; CHS; DOE-NRSC; EPFL; Georgia Tech; HSE-a; ISU; MIT; NASA-ARC; NSF; ORC Worldwide; OUHSC-IBC; Penn-EHRS; TU Delft; UBC; UC; UCI; UCSB; UD; VCU).

The recommendations for respiratory protection range from the usage of disposable masks with type N95 filters (S: CHS; NASA-ARC) to half masks with type P100 cartridges (S: CHS; DOE-NRSC). In cases of high load, i.e. if the nanoparticle concentration is very high or information of the adequateness of the respirator to the specific type of nanoparticles are missing, the use of a breathing apparatus, which is provided with clean air from an independent source, is preferred (S: HSE-a). This breathing apparatus is composed of a full-face mask with a compressed air supply (S: HSE-a). Also the need of a powered air-purifying respirator (PAPR) in conjunction with either a flexible hood, which covers head, shoulders and upper torso, or a full-facepiece is stated (S: ORC Worldwide). Predominantly P100 filters are approved (S: CHS; DOE-NRSC; UCI; UCSB), but also type N95 (S: CHS; NASA-ARC), N-100 (S: UCI; UCSB) and R-100 filters (S: UCI; UCSB) are mentioned. Regarding respiratory protection, comparable European and Australian standards exist for filters, named P2 and P3 (G: BAuA / VCI; HMUELV; Safe Work Australia)

The range of respiratory protection described by specific nanomaterial guidelines related to laboratories is extended by several general nanomaterial guidelines. In two documents, the opinion is advanced that the usage of respiratory protection is only necessary for cleaning of large spills (G: Hallock et al., 2009; PENNSTATE). In contrast to this statement, a mask with an assigned protection factor (APF) 40 or higher is recommended as a minimum standard (G: HSE-b). It is suggested that the respirator shall be used with either a flexible screen that covers head, shoulders and the upper torso, or a properly adjusted full face shield (G: IRSST). Moreover, an expert opinion is recommended to ensure a sufficient protection level according to the respective risk (G: IRSST).

One general nanomaterial guideline suggests selecting respiratory protection according to a selection chart, which was provided by the guideline itself as following (G: MHLW):

1. Respiratory protection with APF (assigned protection factor) of 10 or higher is required for handling nanomaterials in a closed system, automation of manufacturing processes and the use of nanomaterials embedded in resins. This includes replaceable half-face type masks and disposable dust masks (G: MHLW).

[12] The specific aspects of the guidelines can be found in Annex IX.

2. Respiratory protection with APF of 50 or higher is needed if a LEV is utilized. Options for respiratory protection are for instance half facepiece, fan-assisted PAPR, supplied air-masks as well as replaceable full-face type dust masks.

3. In the case of specialized operations or high exposure concentrations, for instance occurring during cleaning operations or collecting and recycling products, respiratory protections with APF of 100 to 1,000 or even higher are suggested. These APF values can be provided by full facepiece and hood type fan-assisted PAPR, supplied-air respirator and pressure demand-type airline mask (G: MHLW). The fit of the used mask ought to be tested every time of wearing (G: MHLW).

The wearing of gloves is also regarded as necessary by all specific nanomaterial guidelines applicable for laboratories addressing this point (S: AIST; CHS; EPFL; Georgia Tech; ISU; MIT; NASA-ARC; NSF; ORC Worldwide; OUHSC-IBC; Penn-EHRS; TU Delft; UBC; UC; UCI; UCSB; UD; VCU). The gloves should be impermeable (S: AIST). The preferential material is nitrile (S: CHS; DOE-NRSC; ORC Worldwide; UBC; UD; VCU). Further recommended materials are latex (S: UBC; UD; VCU) or chemical resistant triple polymer (S: UBC). The glove material should be chosen according to the chemical compatibility to the respective nanomaterial (S: ORC Worldwide; UBC). In a number of reports, the wearing of a double pair of gloves is favored, which is graduated from a double glove wearing suggestion in cases of strong skin contact (S: MIT) to two sets of gloves as minimal requirement (S: TU Delft). The gloves should both cover the hands and overlap the sleeves of the lab coat (S: ISU; VCU). It is also recommended that the gloves should be removed inside the closed system, for instance the enclosing hood (S: ORC Worldwide).

Supplementary, in a general nanomaterial guideline, which is also applicable for laboratories, double gloves made from different materials with latex and nitrile or polypropylenes are suggested (G: NanoSafe Australia). Another guideline presents a glove management system, whose key elements include maintenance, storage, removal, disposal, training, ergonomics, material selection and the exposure/task scenario (G: Safe Work Australia). When handling liquids, nitrile gloves with extended sleeves are regarded as a good option (G: Safe Work Australia). However, gloves shall be chosen after considering the resistance to chemical attack of both nanomaterial and liquid (G: Safe Work Australia).

Safety glasses or face shields are suggested for eye protection in the predominant number of specific nanomaterial guidelines for laboratories (S: AIST; CHS; DOE-NRSC; Georgia Tech; VCU; UBC; UC). In two general nanomaterial guidelines, the need for protective googles with side-protection is highlighted (G: BAuA / VCI; Safe Work Australia).

Regarding footwear, the wearing of closed shoes is mostly recommended preferably from none or low permeability material (S: AIST; CHS; DOE-NRSC). An additional coverage of the shoes with disposable boots (S: EPFL; UBC) may be used to prevent tracking nanomaterials from the laboratory area.

The recommendation for shoe material is specified in a general nanomaterial guideline also applicable for laboratories, in which shoes made of neoprene material are suggested (G: NanoSafe Australia).

As further protection measures, predominantly laboratory coats, disposable laboratory coats (S: MIT) or disposable overalls are listed (S: UD; VCU). It is recommended by one guideline, that the protective clothing should be impermeable (S: AIST). Another guideline suggests utilizing disposable overalls, which could be made up of tyvek textile (S: UD). However, one report controversially leaves the usage of a laboratory coat or a long sleeved shirt with buttons on the back to one’s decision (S: EPFL).

It is pointed out in general nanomaterial guidelines also applicable for laboratories that the laboratory coats shall not consist of cotton, wool or knitted materials (G: HSE-b; MHLW; OSHA-EUROPA). In one guideline, it is suggested to enhance the protective effect by wearing double overalls from different materials, i.e. to wear a supplementary overall from tyvex or polypropylene over a fabric overall (G: NanoSafe Australia).

Further PPE may be hair and beard protection (S: UBC), long trousers without cuffs (S: CHS; DOE-NRSC), long sleeved shirts (S: CHS; DOE-NRSC; Penn-EHRS) or aprons (S: NSF).

In the general nanomaterial guidelines applicable also for the laboratory scale, it is generally mentioned that the protective clothing should cover the full body or, more precisely, all areas of skin (G: NanoSafe Australia; HMUELV).

One specific nanomaterial guideline for laboratories highlights that wounds or lesions on the skin as well as dermatological diseases shall be in each case covered.

9. Medical Surveillance[13]

In one general guideline for nanomaterials, several potential disease outcomes are named including the acute and chronic immune system responses of inflammation, allergy and autoimmunity to viral-sized monodispersed nanoparticles and their bacterial-sized aggregates, respiratory, skin and gastrointestinal related disorders (e.g. liver dysfunction following sequestration of circulating particulates), neurological disorders as well as the potential for cancer of several different types due to oxidative damage to DNA and the tumour promoting events of chronic inflammation and wound repair from ongoing tissue damage (G: Safe Work Australia).

The issue of health monitoring of the exposed workers was addressed in several specific nanomaterial guidelines for laboratories (S: CHS; DOE-NRSC; EPFL; Georgia Tech; HSE-a; UC; UD).

It is recommended that the potentially exposed employees pay especially attention to the onset of potentially chronic effects of the respective nanomaterial (S: Georgia Tech). A medical surveillance can be requested by a responsible person for example the manager of the project if necessary (S: EPFL).

It is also thinkable that the medical recording is performed by a medical director. The medical director takes care of a health monitoring program and performs a periodic medical surveillance of pulmonary, renal, liver and haematopoietic functions (S: DOE-NRSC).

It is stated that one can determine the need for and the specific type of health monitoring by performing a risk assessment (S: HSE-a). One guideline states that health monitoring can ensure the detection of any health effects at an early stage and consequently the reduction of the likelihood of long-term harm (S: HSE-a). However, the required parameters of this health monitoring are not addressed (S: HSE-a).

It is furthermore specifically recommended that the personnel should receive medical permission from a medical doctor before being fitted with a respirator (S: CHS). A differentiated view on the medical surveillance is presented in another guideline, which points out that the medical surveillance should be classified on basis of the potential exposure routes of the nanomaterials (S: UC). One guideline recommends that the special medical examination for the respective nanomaterial shall be received based on the substance category applicable to one of the existing special medical examinations (S: AIST). The employer shall implement regular health examinations under the Industrial Safety and Health Law or the Pneumoconiosis Law (in Japan), and recognize the latest health conditions of the worker (G MHLW).

[13] The specific aspects of the guidelines can be found in Annex X.

It is mentioned that allergenic or carcinogenic particles should be screened specifically since even tiny quantities of these particles may be biologically significant (S: UC). It is added by way of explanation that skin contact can occur easily during the handling of suspension of nanoparticles or dry powders (S: UC). Furthermore, it is determined that pregnant workers are not allowed to work with nanomaterials (S: UC).

Regarding first aid, the following recommendations are given by one specific nanomaterial guideline for laboratories: 1) If nanomaterials get into the eye, they shall be flushed and rinsed with plenty of water; 2) and 3) In case of inhalation or ingestion, they suggest gargling, washing and rinsing the mouth thoroughly, whereby for 2) inhalation, the movement to a clean air area and for 3) ingestion, spitting out is expedient; 4) If nanomaterials are adhered to the skin, they ought to be washed with soap or wiped off with cleansing cream (S: AIST) (G: MHLW).

10. Transport[14]

Several specific nanomaterial guidelines for laboratories agree in the opinion that nanoscaled materials shall be transported like normal chemicals (S: TU-Delft), i.e. in closed, labelled containers (S: CHS; ISU; MIT; Penn-EHRS). In one guideline, the requirements are explained explicitly (S: DOE-NRSC). Nanomaterials shall be transported according to 49 Code of Federal Regulations (CFR) 100-185 and, if shipped by air, also according to the International Civil Aviation Organizaton (ICAO) (S: DOE-NRSC). The respective nanomaterial shall be double packaged whereas the outer and inner package shall meet the definition of a Package Group (PG I) type package (S: DOE-NRSC). It is suggested to apply adequate safety measures equivalent to the measures for chemical materials in order to protect the container or package from damages due to earthquake and fire (S: AIST). One mentioned option refers to the outer package, which shall be filled with a shock and liquid absorbing material both to protect the inner container from damage and to absorb potential leakages (S: DOE-NRSC). This leakage shall be moreover prevented by a tight sealing of the innermost container (S: DOE-NRSC).

11. Waste Disposal[15]

Several specific nanomaterial guidelines for laboratories suggest the general disposal of nanomaterials as chemical or hazardous waste according to local legal requirements (S: CHS; Georgia Tech; ISU; NASA-ARC, NSF; Penn-EHRS; UC; UCI;, UD).

It is further recommended by one guideline to treat nanomaterial waste including dust filters, collected waste liquid and cloth, appropriately to prevent secondary contamination and to dispose this waste according to the waste separation method specified by the respective institutes (S: AIST).

Several guidelines also highlight a gradation for disposal treatment. It is one option to treat quantities of nanomaterials with low water solubility exceeding the milligram range as chemical waste (S: TU-Delft). Nanomaterials with high water solubility shall be treated according to the toxicity class of the macroscopic material (S: TU-Delft).

It is also suggested to dispose nanomaterials in solution according to the hazardous waste procedures for the solvent (S: UCI; UCSB).

[14] The specific aspects of the guidelines can be found in Annex XI.

[15] The specific aspects of the guidelines can be found in Annex XII.

Regarding the aspect that there are no specific regulations that apply to nanomaterial waste, one guideline suggests waste management of the following nanomaterial waste streams: a) pure nanomaterials, b) items contaminated with nanomaterials, c) liquid suspensions containing nanomaterials and d) solid matrixes with nanomaterials friable or attached to the surface (S: MIT). In this guideline, the treatment of nanomaterials as hazardous waste is generally recommended (S: MIT). The guideline does not apply to nanomaterials embedded in a solid matrix that cannot reasonably be expected to break free or leach out when they contact air or water (S: MIT).

The chemical properties of the respective nanomaterial can determine what kind of disposal approach is to be followed. It is suggested to characterize the nanomaterials according to their characteristics as either hazardous or nonhazardous waste based on the requirements in 40 CFR 261.10-38 or equivalent state regulations (S: DOE-NRSC).

Specifically, it is suggested to treat contaminated liquid and solid wastes in an appropriate way to inactivate the nanomaterial (S: EPFL). However, no details are provided about the way of inactivation and the type of nanomaterials addressed.

Similarly, it is recommended to dispose the nanomaterial as hazardous waste if the chemical or mixture is regulated as such by environmental regulations (S: ORC Worldwide). Otherwise, a disposal as special waste shall be chosen such as incineration, chemical treatment or immobilization (S: ORC Worldwide). A special consulting is required for a larger amount of waste (S: ORC Worldwide).

Several recommendations for the disposal of nanomaterial packaging and contaminated materials exist. One option is to collect these materials in a double bag or double container, label and seal these materials for disposal (S: CHS; DOE-NRSC; Georgia Tech; MIT). This double-bag can be for instance a 6 ml plastic bag (S: Georgia Tech). Another guideline describes a singular packing in a bag or bucket (S: ORC Worldwide). Contaminated nanomaterials shall be either disposed as hazardous waste (S: TU-Delft) or through incineration (S: VCU).

In a number of general nanomaterial guidelines also applicable to laboratories, the disposal of nanoscale materials as hazardous waste is likewise recommended (G: Hallock et al., 2009; HSE-b; NanoSafe Australia; Surrey-ATI).

A single guideline stated that the disposal ought to follow the requirements for the respective bulk material since they are still no specific guidelines for disposal of waste materials existing (G: PENNSTATE). However, the disposal shall be based on a previous consultation of the EHS office (G: PENNSTATE). Exceptions are nanomaterials which contain toxic metals or flammable carbon. These materials shall be treated as hazardous waste (G: PENNSTATE).

The disposal of nanomaterials with metal and metal oxide constituents, like quantum dots or zinc oxide, is for instance restricted in Australia since they are assumed to be potent biocides (G: NanoSafe Australia). Nanomaterials can finally be bound within some matrix like concrete and be disposed in a licensed land-fill scape (G: NanoSafe Australia).

Another suggestion is related to carbon nanotubes which can be incinerated as hazardous waste in a high temperature incinerator since heating above 500 °C oxidizes these materials completely (G: HSE-b). The disposal conditions as well as the incineration temperature shall be documented thoroughly (G: HSE-b).

12. Documentation[16]

Several recommendations regarding the correct documentation are provided by several specific nanomaterial guidelines for laboratory application. Documents, which shall be read by all employees working with nanomaterials and kept in the laboratory working areas permanently, can be the laboratory safety plan or manual (S: AIST; ISU; NASA-ARC), chemical hygiene plan (S: DOE-NRSC; VCU), standard operating procedures (SOP) (S: ISU; NASA-ARC; VCU; Surrey-ATI) and material safety data sheets (MSDS) (S: DOE-NRSC; Georgia Tech; MIT; NASA-ARC; UCI; UCSB).

Additionally, Job Hazard Analysis Worksheets (JHA) can be required for specific laboratory procedures (S: DOE-NRSC; NASA-ARC).

In order to better ensure understanding and competence, it is suggested that specific procedural requirements shall be incorporated into written procedures (S: DOE-NRSC). However, this recommendation is given on a general basis with no details indicating, which work steps or manufacturing approaches are addressed.

It is further suggested to document not only incidents (S: NSF), but also the training (S: NSF) and the exposure of the nanoparticle-exposed employees (S: DOE-NRSC).

Protocols including the *in vivo* usage of nanoparticles shall suitably include completion of IACUC Hazardous Chemical Information Page (S: OUHSC-IBC; VCU). Furthermore, the approval through the Institutional Animal Care and Use Committee and the Institutional Biosafety Committee (IBC) is required (S: OUHSC-IBC; VCU). Protocols, which involve the administration of nanoparticles to humans, specifically require Institutional Review Board (IRB) approval (S: OUHSC-IBC).

Other aspects of documentation are mentioned in general nanomaterial guidelines also applicable for laboratory research. The compiled protocol shall include information on performed tests (G: HMUELV), protection measures (G: HMUELV; PENNSTATE) and nanomaterial properties like particle size distribution, composition and configuration (G: PENNSTATE). It is recommended that this protocol, which contains specific requirements addressing health and safety protection (G: PENNSTATE), shall be either shown to the supervisor (G: Surrey-ATI) or the environmental health and safety office (G: PENNSTATE). Furthermore, the name of the worker, the engaged period of work and the general description of the nanomaterial-related work, shall be documented (G: MHLW). It is suggested to keep the documentation for a prolonged period (G: MHLW).

The generation of an internal database, which contains a series of documents, is reasonable (G: HMUELV). It is recommended to insert documents about the nanomaterial properties, toxicological and epidemiological data, safety tests and measures, measures for exposure mitigation, MSDS, product utility, the number of exposed employees, quality assurance and the question of liability in liability case (G: HMUELV).

In general nanomaterial guidelines, which are also applicable for laboratories, the quality of MSDS is regarded controversially. It is argued that MSDS may not contain accurate information (G: PENNSTATE). MSDS often refer to micron scale materials whereas the properties from microscale and nanoscale materials differ (G: Hallock et al., 2009; PENNSTATE). The composition of the micro- and nanoscale carbon materials is applied as comparison. In one commercially available carbon material, graphite is composed of coarse particle, whereas CNTs have a fiber shape (G: PENNSTATE). These forms also differ in their toxicity (G: PENNSTATE).

[16] The specific aspects of the guidelines can be found in Annex XIII.

MSDS are on the one hand regarded as important sources of information (G: OSHA-EUROPA) and on the other hand considered critically since the MSDS at present only refer to the macroscale level of a substance and are not adapted to the unique properties of nanomaterials differing from the original substance (G: Hoyt and Mason, 2008).

SECTION 4: CONCLUSION

A compilation of nanomaterial exposure mitigation guidelines relating to laboratories is presented in this document. It was of special interest to provide a broad overview of recently published literature referring to this topic since no globally standardized protection measures for handling nanomaterials are determined yet.

The content and structure of the analysed guidelines is primarily based on typical guideline concepts. The various aspects, which are mentioned in these guidelines, refer to the precautionary approach, categorization, assessment of nanospecific and physical hazards, measures according to the STOP principle (i.e. substitution (here, use of safer manufacturing approaches), technical measures, organizational measures and personal protective equipment), medical surveillance, transport, waste disposal and documentation of the taken measures.

The reported opinions on the majority of aspects agree on many points and exhibit basically only a minor deviation. As an example, it is generally regarded as essential to use precautionary measures to minimize risk in laboratories. Further aspects, which are regarded to be essential, refer to the general application of risk assessment, use of safer manufacturing approaches, technical and organizational measures and personal protective equipment. A consensus also exists on routine cleaning by vacuuming and wet wiping as well as on cleaning hygiene of the employees by regular hand washing. A disposal of nanomaterials as hazardous or chemical waste is likewise suggested by the majority of guidelines.

However, a large variation exists regarding several aspects. In the paragraph on categorization, the simplified view of an equal potential toxicity assumption of nanomaterials is extended to a distinction of defined risk levels considering the specific properties of the respective nanomaterial for instance size, chemical composition and surface area.

For risk assessment, a case by case approach is suggested. Furthermore, the application of a control banding approach for a qualitative risk assessment is recommended, which is based on the use of a limited number of factors for evaluating the risk level in order to reduce the complexity and increase the applicability for non-experts.

Regarding the risk assessment, a high diversity of opinions on the necessary contents is mentioned. A large variation of recommendations is similarly given in respect to respiratory protection ranging from disposable masks with type N95 filters to half masks with type P100 cartridges.

Additionally, singular noticeable opinions on some aspects have been detected. For instance, one guideline only recommends precautionary measures if the mass of the nanomaterial sample exceeds the milligram range. Specific suggestions for technical measures are a stable depression of 6 mm water column in the laboratory area and a ventilation system with 6 to 12 air changes per hour. Regarding organizational measures, it is stated that carbon nanoparticles of more than 1 g shall be stored in sealed metal containers due to their electrostatic activity. Similarly, specific recommendations for the cleaning agent like iso-propanol, water, cleaning agents compatible to the respective material are given. The cleaning measures shall be different above a threshold of 5 mg nanopowder or 5 ml nanomaterial solution as well as at a cleaning time of more than 5 min. Specific personal protective equipment like neoprene shoes or disposable overalls from tyvex textile is likewise suggested.

One can conclude that the reviewed guidelines mainly agree in the basic issues of occupational safety with respect to nanomaterials in laboratory scale. These issues can therefore be regarded as a consolidated consensus.

In other aspects, a large range of different recommendations on health and safety measures can be found. The suggestions on the one side of the range, where lesser protection measures are mentioned, are possibly more suited to deal with low hazard nanomaterials.

Some very specific remarks appear only sporadically and hence should be regarded carefully. They provide very detailed information, which might be helpful to determine precise measures.

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ANNEX I. Overview of Laboratories Guidelines related to Nanomaterials

1. Category S(pecific): specific nanomaterial guidelines relating to laboratories

Acronym	Institution	Guideline title	Country	Publication date
AIST	National Institute of Advanced Industrial Science and Technology	Guideline for Prevention against Exposure to Nanomaterials	Japan	2009
CHS	CHS (Center for High-Rate Nanomanufacturing)	Interim Best Practices for Working with Nanoparticles	Organization	2008
DOE-NRSC	DOE (Department of Energy) Nanoscale Science Research Centers	Approach to Nanomaterial ES&H	USA	2008
EPFL	EPFL (École polytechnique fédérale de Lausanne)	Nanoparticles: a security guide	Switzerland	2007
Georgia Tech	Georgia Institute of Technology	Nanotechnology Safety Resources	USA	accessed at 19th Jun 2009
HSE-a	HSE (Health and Safety Executive)	Nanotechnology	United Kingdom	2004
ISU	Iowa State University	Nanomaterials Health and Safety Guidelines	USA	accessed at 19th Jun 2009
MIT	MIT (Massachusetts Institute of Technology)	Best Practices for Handling Nanomaterials in Laboratories	USA	2008
NASA-ARC	NASA (National Aeronautics and Space Administration)	Nanomaterials Safety and Health Guideline for Carbon-based nanomaterials	USA	2007
NSF	NSF (National Science Foundation)	Environmental, Health and Safety guidelines for NSF Nanoscale Science and Engineering Research Centers	USA	accessed at 9th Jul 2009
ORC Worldwide	ORC (Organization Resources Councelors)	Guidelines for Safe Handling of Nanoparticles in Laboratories	Organization	2005
OUHSC-IBC	University of Oklahoma Health Science Center	Nanoparticle Handling Guidelines	USA	accessed at 12th Mar 2009
Penn-EHRS	EHRS (Environmental Health and Radiation Safety), University of Pennsylvania	Nanoparticle Handling Fact Sheet	USA	2008
TU Delft	Delft University of Technology	TNW Nanosafety Guidelines	Netherlands	2008
UBC	University of British Columbia	AMPEL Nanofabrication Facility Members' Laboratory Guide	Canada	2004
UC	University of California (published as ISO TC 229 WG 3)	Laboratory Management - Draft Health Safety Guidelines for Nanotechnology research	USA	2004
UCI	University of California Irvine	Nanotechnology: Guidelines for Safe Research Practices	USA	2008
UCSB	UCSB (University of California Santa Barbara)	Laboratory Safety Fact Sheet 32# - Engineered Nanomaterials: Guidelines for Safe Research Practices	USA	accessed at 12th Mar 2009
UD	University of Dayton	Nano Technology - Health & Safety	USA	2006
VCU	VCU (Virginia Commonwealth University)	Nanotechnology and Nanoparticles	USA	2007

2. Category G(eneral): general nanomaterial guidelines with regards/ applicable to laboratories

Acronym	Institution	Guideline title	Country	Publication date
BAuA / VCI	Federal Institute for Occupational Safety and Health (BAuA) German Chemical Industry Association (VCI)	Guidance for Handling and Use of Nanomaterials at the Workplace	Germany	2007
Hallock et al., 2009	Hallock et al., Journal of Chemical Health & Safety	Potential risks of nanomaterials and how to safely handle materials of uncertain toxicity		2009
HMUELV	Ministry for Economics, Transportation and State Development for the State of Hessen	Innovationsfördernde Good-Practice-Ansätze zum verantwortlichen Umgang mit Nanomaterialien	Germany	2008
Hoyt and Mason, 2008	Hoyt and Mason, Journal of Chemical Health & Safety	Nanotechnology - Emerging health issues		2008
HSE-b	HSE (Health and Safety Executive)	Risk management of carbon nanotubes	United Kingdom	2009
IRSST	Institut de recherche Robert-Sauvé en santé et en sécurité du travail.	Best Practices Guide to Synthetic Nanoparticle Risk Management	Canada	2009
MHLW	Ministry of Health, Labour and Welfare	Measures for Prevention of Exposure to Nanomaterials at Workplaces	Japan	2009
NanoSafe Australia	NanoSafe Australia Network	Current OHS Best Practices for the Australian Nanotechnology Industry	Australia	2007
NIOSH, 2009	U.S. National Institute for Occupational Safety and Health	Approaches to Safe Nanotechnology: Managing the Health and Safety Concerns	USA	2009
OSHA-EUROPA	European Agency for Safety and Health at work (OSHA)	Workplace exposure to nanoparticles	organization	2009, accessed at 5th Jun 2009
PENNSTATE	Pennsylvania State University	Nanomaterials: Potential Risks and Safe Handling Methods	USA	2004 (accessed at 3rd Jun 2009)
Safe Work Australia	Safe Work Australia	Engineered nanomaterials: evidence on the effectiveness of workplace controls to prevent exposure	Australia	2009
Schulte et al., 2008	Schulte et al., Scand J Work Environ Health	Sharpening the focus on occupational safety and health in nanotechnology		2008
Surrey-ATI	University of Surrey, ATI (Advanced Technology Institute)	Code of practice for working with Nanoparticles	United Kingdom	2007

3. Category L(aboratories): general laboratory guidelines with regards/ applicable to nanomaterial

Acronym	Institution	Guideline title	Country	Publication date
AGS-BMAS	Federal ministry for labour and social affairs, GMBl Nr.15 S.295-314 (02.04.2008)	TRGS (technical rule for hazardous substances) 526 - laboratories	Germany	2008
DGUV	statutory employment accident insurance fund for the Chemical Industry (BG Chemie) / German Social Accident Insurance (DGUV), Jedermann-Verlag, Heidelberg	BGI/GUV-I 850-0 Sicheres Arbeiten in Laboratorien	Germany	2008

4. Addressed issues in guidelines of Category S(pecific)

Acronym	0 Definition	1 Precautionary approach	2 Classification	3 Risk assessment	4 Physical hazards	5 Safer manufacturing approaches	6 Technical measures	7 Organizational measures	7.1 Labeling	7.2 Personal training	7.3 Cleaning	8 Personal protective equipment	9 Medical surveillance	10 Transport	11 Waste	12 Documentation
AIST	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
CHS	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
DOE-NRSC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
EPFL	✓	✓	✓			✓	✓	✓		✓	✓	✓	✓		✓	
Georgia Tech	✓	✓	✓		✓	✓	✓	✓			✓	✓	✓		✓	✓
HSE-a		✓	✓	✓	✓	✓	✓	✓		✓		✓	✓			
ISU		✓			✓		✓				✓	✓		✓	✓	✓
MIT	✓	✓			✓		✓		✓		✓	✓		✓	✓	✓
NASA-ARC	✓	✓	✓				✓	✓		✓	✓	✓			✓	✓
NSF	✓	✓				✓	✓			✓		✓			✓	✓
ORC Worldwide	✓		✓	✓		✓	✓	✓			✓	✓			✓	
OUHSC-IBC	✓	✓					✓	✓			✓	✓		✓		✓
Penn-EHRS			✓				✓	✓			✓	✓		✓	✓	
TU Delft	✓	✓	✓		✓	✓	✓	✓			✓	✓		✓	✓	
UBC							✓	✓	✓	✓	✓	✓				
UC	✓				✓		✓	✓			✓	✓	✓	✓	✓	
UCI	✓	✓	✓			✓	✓	✓		✓	✓	✓			✓	✓
UCSB	✓	✓	✓			✓	✓	✓		✓	✓	✓			✓	✓
UD	✓			✓		✓	✓	✓		✓	✓	✓	✓		✓	
VCU	✓			✓		✓	✓			✓	✓	✓			✓	✓

Note 1: ✓(addressed); blank (not addressed)

5. Addressed issues in guidelines of Category G(eneral)

Acronym	0 Definition	1 Precautionary approach	2 Classification	3 Risk assessment	4 Physical hazards	5 Safer manufacturing approaches	6 Technical measures	7 Organizational measures	7.1 Labeling	7.2 Personal training	7.3 Cleaning	8 Personal protective equipment	9 Medical surveillance	10 Transport	11 Waste	12 Documentation
BAuA / VCI	✓					✓	✓					✓				
Hallock et al., 2009	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓		✓	✓	✓
HMUELV	✓		✓	✓		✓	✓	✓		✓	✓	✓				✓
Hoyt and Mason, 2008						✓	✓				✓	✓			✓	✓
HSE-b	✓	✓		✓		✓	✓	✓		✓	✓	✓			✓	✓
IRSST	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓
MHLW	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓
NanoSafe Australia		✓	✓		✓	no substitution	✓	✓			✓	✓			✓	
NIOSH, 2009	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
OSHA-EUROPA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓
PENNSTATE	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓
Safe Work Australia	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Schulte et al., 2008		✓	✓	✓			✓	✓				✓	✓			
Surrey-ATI	✓	✓	✓	✓		✓	✓	✓			✓	✓			✓	✓

6. Addressed issues in guidelines of Category L(aboratories)

Acronym	0 Definition	1 Precautionary approach	2 Classification	3 Risk assessment	4 Physical hazards	5 Safer manufacturing approaches	6 Technical measures	7 Organizational measures	7.1 Labeling	7.2 Personal training	7.3 Cleaning	8 Personal protective equipment	9 Medical surveillance	10 Transport	11 Waste	12 Documentation
AGS-BMAS		✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DGUV		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

ANNEX II. Precautionary Approach

The application of the precautionary approach to the handling of nanomaterials is recommended by a number of guidelines regarding environmental and human health impact.

1. **Category S(pecific)** nanomaterial guidelines

guideline documents	precautionary approach
AIST	✓
CHS	✓, may be toxic
DOE-NSRC	treat like acutely toxic in short run and chronically toxic in long run; particles may be carcinogenic
EPFL	✓
Georgia Tech	✓
HSE-a	✓
ISU	✓, treat as toxic
MIT	✓
NASA-ARC	✓
NSF	✓
ORC Worldwide	
OUHSC-IBC	✓
Penn-EHRS	
TU Delft	✓, additional precaution if more than 1 g CNT
UBC	
UC	
UCI	✓
UCSB	✓
UD	
VCU	

2. **Category G(eneral)** nanomaterial guidelines

guideline documents	precautionary approach
BAuA / VCI	
Hallock et al., 2009	✓, uncertain toxicity, potentially toxic, pulmonary inflammation, granulomas, fibrosis
HMUELV	
Hoyt and Mason, 2008	
HSE-b	✓
IRSST	✓
MHLW	potentially toxic
NanoSafe Australia	✓
NIOSH	✓
OSHA-EUROPA	✓, acute and chronic toxicity, sensitisation, reproductive toxicity, genotoxicity, cancerogenicity
PENNSTATE	✓, treat like toxic
Safe Work Australia	A precautionary approach guided by reference to the 'precautionary principle' shall be adopted in order to limit workplace exposure. However, once data about the health and safety risks have been determined and defined, the principle of 'As Low As Reasonably Practicable' (ALARP) can be adopted.
Schulte et al., 2008	✓
Surrey-ATI	✓

3. **Category L(aboratories)** guidelines

guideline documents	precautionary approach
AGS-BMAS	✓, treat like acute and chronically toxic, flammable, pyrophorous, explosive
DGUV	✓, treat like acute and chronically toxic, flammable, pyrophorous, explosive; treat nano like new substances

ANNEX III. Categorization

To treat the nanomaterials as potentially toxic due to some of their unknown properties, a number of proposals to grade the potential hazard exist.

1. Category S(pecific) nanomaterial guidelines

guideline documents	classification		
	general	amount/size mass/number of particles	physical state
AIST	✓	handling quantities (per an experiment); threshold value of the quantity presently 1 g	Solid materials with embedded nanomaterials (handling category 1) < work operated in enclosed system (handling category 2) < nanomaterials suspended in liquids (handling category 3) < dust amount 1 g or less (handling category 4) < dust amount more than 1 g (handling category 5)
CHS			solid < liquid < dust
DOE-NRSC	✓		solid matters with embedded nanostructures < solid with nanostructures fixed to surface < nanoparticles suspended in liquid < particles, agglomerates or aggregates
EPFL	✓		dust or liquid
Georgia Tech	✓	size of insoluble particles, reactivity of surface	✓
HSE-a	✓	✓, mass/number of particles	✓
ISU			
MIT			
NASA-ARC	✓	✓, dry particle amount more than 1 g	solid, liquid < dust
NSF			
ORC Worldwide	✓		liquid < dust
OUHSC-IBC			
Penn-EHRS	✓		
TU Delft	✓	✓, primary particle units smaller than 100 nm	encapsuled or immobilized < liquid < dust
UBC			
UC			
UCI	✓		✓
UCSB	✓		✓
UD			
VCU			

2. Category G(eneral) nanomaterial guidelines

guideline documents	classification		
	general	amount/size mass/number of particles	physical state
BAuA / VCI			
Hallock et al., 2009	✓	size (particles < 10 nm reach alveolar spaces of lung) particles ≤ 1μm enter epidermis	solid materials with embedded nanomaterials < solid materials with nanostructure bound to the surface < liquid suspensions
HMUELV	✓		dust < liquid medium or matrix
Hoyt and Mason, 2008			
HSE-b			
IRSST		surface: area, properties, and coverage; number of particles, size, granulometric distribution, concentration, chemical composition, (purities, impurities), Zeta charge/potential, reactivity, functional groupings, presence of metals/Redox potential, Potential to generate free radicals, solubility, shape, porosity, degree of agglomeration/aggregation, biopersistence, crystalline structure, hydrophilicity/hydrophobicity, age of particles	
MHLW			solid including aggregate/agglomerate
NanoSafe Australia	✓	particle size	
NIOSH	✓		
OSHA-EUROPA	✓	morphology, size, surface, solubility, agglomeration,mass, surface conditions, particle concentration, volume etc.	in unsoluble matrix < free
PENNSTATE	✓	particle size	some types of nanomaterials can be toxic if they are not bound by substrate and they are available to the body
Safe Work Australia			
Schulte et al., 2008	✓	size, surface area, shape, solubility, surface reactivity, charge, attached functional groups, crystalline structure, agglomeration status, contaminants	
Surrey-ATI	✓	particle size	devices comprised of nanostructures (integrated circuits, composite materials) < gas phase, liquids, powders

3. Category L(aboratories) guidelines

guideline documents	classification		
	general	amount/size mass/number of particles	physical state
AGS-BMAS			
DGUV			

ANNEX IV. Risk Assessment

Performing a risk assessment is generally supported by a high number of guidelines.

1. **Category S(pecific)** nanomaterial guidelines

guideline documents	risk assessment
AIST	
CHS	
DOE-NRSC	✓, description of work, subject matter experts, hazards and uncertainties, hazard controls: engineering controls, design reviews, formal procedures, use of PPE, training, other administrative contols, criteria for work-change control, evaluate potential for worker exposure
EPFL	
Georgia Tech	
HSE-a	✓, scientific information and past experience necessary, regular review, health monitoring
ISU	
MIT	
NASA-ARC	
NSF	
ORC Worldwide	✓, physical form (dry powder, liquid solution/slurry), nanoparticle size range, potential exposure routes, (inhalation, skin or eye contact), toxicity, work process procedures, engineering controls, use of electrical/magnetic fields or temperature gradients, risk of fire or explosion, disposal
OUHSC-IBC	
Penn-EHRS	
TU Delft	
UBC	
UC	
UCI	
UCSB	
UD	✓
VCU	✓, individually for all nanoparticles and processes involved

2. **Category G(eneral)** nanomaterial guidelines

guideline documents	risk assessment
BAuA / VCI	
Hallock et al., 2009	✓, obtain current toxicity information by web search
HMUELV	✓, single case assessment; physico-chemical, toxicologically and ecotoxicologically properties
Hoyt and Mason, 2008	
HSE-b	✓
IRSST	repeat and refine risk assessment regularly to account for new scientific knowledge and practical modifications related to specific conditions of the work environment; a case by case approach is to be preferred; control banding
MHLW	currently available data and knowledge information on electron micrographs, particle size, and specific surface area, etc., measuremnet of concentration of nanomaterials in working environment
NanoSafe Australia	
NIOSH	✓
OSHA-EUROPA	✓, physico-chemical characterization, particle size distribution, -morphology, -composition, -surface area, -number conc., -reactivity in solution, -structure
PENNSTATE	✓, review all available information, particle size distribution, particle composition and configuration, based on most current toxicological data
Safe Work Australia	Then in later development/production activities, and once the toxicological and other relevant properties of the nanomaterial have been determined, the control measures should be reviewed through a thorough process-specific risk assessment and, if warranted, modified accordingly. A complete life-cycle analysis of the nanomaterial should always be made to identify potential ‘hotspots’ of worker exposure, including construction, packaging, manufacturing, handling, maintenance or cleaning work, and end-of-life and safe disposal issues. There are a whole range of jobs and tasks need to be considered. Existing ventilation systems that are effective for extracting ultrafine dusts in other industries should also be employed and optimally maintained where appropriate, in order to reduce exposure to engineered nanomaterials. Control banding approach for research and early development activities involving nanomaterials, where similar control measures shall be used within categories of nanomaterials that have been grouped (“banded”) according to their exposure potential and hazardous properties. If the macroscale material is carcinogenic, then special advice is required. Toxicology can be influenced by particle size, shape, solubility, surface area, chemistry, reactivity. Absorption of nanomaterials could be increased by "surface active" chemicals. The risk assessment shall be in accordance with the existing regulations.
Schulte et al., 2008	exposure assessment
Surrey-ATI	✓, specific to process

3. **Category L(aboratories)** guidelines

guideline documents	risk assessment
AGS-BMAS	
DGUV	✓

ANNEX V. Physical Hazards

In several specific nanomaterial guidelines for laboratories, physical hazards like catalytic effects, fire or explosion are mentioned.

1. **Category S(pecific)** nanomaterial guidelines

guideline documents	physical hazards
AIST	fire, particle dust, explosion
CHS	
DOE-NRSC	fire, explosion
EPFL	---
Georgia Tech	catalytic effects, fire, explosion
HSE-a	catalytic effects, fire, explosion
ISU	explosion, fire, high reactivity of particles
MIT	catalytic effects, fire, explosion
NASA-ARC	
NSF	
ORC Worldwide	
OUHSC-IBC	
Penn-EHRS	
TU Delft	fire and explosion, particles pyrophoric
UBC	
UC	high reactivity, fire, explosion
UCI	
UCSB	
UD	
VCU	

2. **Category G(eneral)** nanomaterial guidelines

guideline documents	physical hazards
BAuA / VCI	
Hallock et al., 2009	fire, explosion
HMUELV	
Hoyt and Mason, 2008	
HSE-b	
IRSST	explosive, flammable, risk of asphyxiation, catalytic potential ignition enery and violence of an explosion influenced by particle size or area,
MHLW	fire and explosion
NanoSafe Australia	explosion, flammability
NIOSH	✓, fire, explosion, catalytic effects
OSHA-EUROPA	catalytic effects, risk of fire and explosion, electrocution, asphyxiation
PENNSTATE	fire, explosion
Safe Work Australia	flammability, explosive, reactivity Hazard testing: self ignition temperature, burning rate and exposive property characterisation
Schulte et al., 2008	
Surrey-ATI	

3. **Category L(aboratories)** guidelines

guideline documents	physical hazards
AGS-BMAS	
DGUV	

ANNEX VI. Safer Manufacturing Approaches

Safer manufacturing approaches are generally recommended by several reports regarding the handling of nanomaterials in laboratory scale, as well as changing the physical condition of the used nanomaterials

1. Category S(pecific) nanomaterial guidelines

guideline documents	safer manufacturing approaches general	exposure-mitigation	produced amount	mitigation of dust release general	physical state (powder->liquid)
AIST	✓	✓		✓	✓, As for an effective measure to prevent exposure, consider applying wet method which treats
CHS		✓		✓	✓
DOE-NRSC		✓		✓	✓
EPFL		✓			
Georgia Tech		✓			
HSE-a	✓	✓			
ISU					
MIT					
NASA-ARC					
NSF		✓			
ORC Worldwide	✓				✓
OUHSC-IBC					
Penn-EHRS					
TU Delft		✓	✓		
UBC					
UC					
UCI	✓				✓
UCSB	✓			✓	✓
UD	✓			✓	
VCU		✓, develp and implement SOPs (standard operating procedures)			

2. Category G(eneral) nanomaterial guidelines

guideline documents	safer manufacturing approaches general	exposure-mitigation	produced amount	mitigation of dust release general	physical state (powder->liquid)
BAuA / VCI	✓				✓, bind powder nanomaterials in liquid or solid media. Use dispersions, pastes or compounds instead of powder substances
Hallock et al., 2009					
HMUELV	✓, replace hazardous against less hazardous substances	✓ (inhalativ), timeline of procedures		✓	✓, replace powder against dispersion, pastes, granules
Hoyt and Mason, 2008	✓				
HSE-b		✓	✓	✓	✓
IRSST	✓, replace hazardous with less hazardous substances, modify type of process				
MHLW	reduce oxygen concentration in manufacturing/ handling experiments; prevent static electricity generation			✓	
NanoSafe Australia	no substitution	✓			
NIOSH	✓				
OSHA-EUROPA	✓	✓			
PENNSTATE		✓		✓	
Safe Work Australia	nanomaterial modification	✓			✓, replace powder against dispersion, pastes, pellets
Schulte et al., 2008					
Surrey-ATI		✓			

3. Category L(aboratories) guidelines

guideline documents	safer manufacturing approaches general	exposure-mitigation	produced amount	mitigation of dust release general	physical state (powder->liquid)
AGS-BMAS	✓				
DGUV	✓				

ANNEX VII. Technical Measures

The need for technical exposure mitigation has been emphasized by all nanomaterial guidelines.

1. **Category S(pecific)** nanomaterial guidelines

Technical measures / Guideline documents	technical measures general	safety equipment	closed system	LEV (local exhaust ventilation) / local exhaust system	clean room	sterile cabinet	biohazard cabinet	microbio-logical safety cabinet
AIST	✓	✓	✓	The use of local exhaust ventilation system with enclosed fume hood is recommended. In some cases, considering the characteristic of the work involved, the installation of push-pull ventilation system is preferable.				
CHS	✓			✓				
DOE-NRSC	✓, exhausted air has to be filtered (HEPA) or otherwise cleaned		✓, negative pressure differential	✓, e.g. "snorkel hood"				
EPFL	✓							
Georgia Tech	✓							
HSE-a	✓			✓ (e.g.fume cupboards)				
ISU	✓							
MIT	✓		✓, particles, suspensions, cleaning contaminated parts of reactors or furnaces	clean parts of reactors and furnaces that are too large for fume hood, also design of special custom enclosure possible (evaluation by health and safety office)				
NASA-ARC	✓		✓	✓, associated with reactors				
NSF	✓							
ORC Worldwide	✓		✓	✓ if open LEV: additional respiratory protection and close localisation to nanoparticle source				
OUHSC-IBC	✓							
Penn-EHRS	✓		✓, vented filtered enclosure, for handling with particles and aerosoles					
TU Delft	✓		✓, (glove box)					
UBC	✓	safety shower, eyewash, first aid kit, fire extinguisher, emergency exits			✓, existing in laboratory			
UC	✓							
UCI	✓			✓				
UCSB	✓			✓				
UD	✓			✓, HEPA-filtered				
VCU	✓	eyewash station according to ANSI and OSHA requirements						

1. Category S(pecific) nanomaterial guidelines (cont. Technical Measures)

Guideline documents \ Technical measures	biological safety cabinet / biosafety cabinet	reactor	furnace	ventilated cabinet	dust collection system	dust hood	local exhaust source
AIST				✓	High-efficiency filter is recommended. Use of an electric dust collector, etc. may be considered if the targeted material can be collected properly.	✓	
CHS	class II type B1 or B2						
DOE-NRSC	✓, type II, exhaust air directly to the exterior (hard duct)						
EPFL							
Georgia Tech							
HSE-a							
ISU	✓, handling of dry nanoparticles			✓, only here use of compressed gas cylinders, with National Fire Protection Association (NFPA) health ratings of three or four allowed			
MIT	class II type A2, B1 oder B2, B2: 100% exhausted -> use of higher amounts of nanoparticles and solvents	with ventilation, if possible: run exhaust gases through liquid bubbler system	with ventilation, if possible: run exhaust gases through liquid bubbler system				
NASA-ARC							
NSF							
ORC Worldwide						less suited than laminar flow or fume hood because small particles behave more like gases or vapors	
OUHSC-IBC	✓						
Penn-EHRS	✓, particles, aerosoles				✓		exhaust from all furnaces used to produce particles must be trapped and connected in local exhaust source
TU Delft							
UBC							
UC							
UCI							
UCSB							
UD							
VCU							

1. Category S(pecific) nanomaterial guidelines (cont. Technical Measures)

Guideline documents \ Technical measures	local exhaust	dedicated exhaust duct	exhaust hood	source enclosure	laminar flow cabinet	laminar flow hood	hood	fume hood
AIST		✓, The exhaust port of the local exhaust ventilation system, etc. shall be connected to a high-efficiency filter to minimize airborne release of nanomaterials to outside area. The local exhaust ventilation system, etc. shall be inspected periodically to ensure the proper operation.		✓		The use of local exhaust ventilation system with enclosed fume hood is recommended. In some cases, considering the characteristic of the work involved, the installation of push-pull ventilation system is preferable.		
CHS						✓		✓
DOE-NRSC	✓		✓			NO horizontal laminar flow hood ("clean bench") that direct a flow of HEPA-filtered air into the user's face, when particles are used	✓, for storage of loose contamination (in sealable container or plastic bag)	
EPFL								
Georgia Tech						✓, HEPA-filtered		
HSE-a								
ISU		✓, handling of fumes / gases						✓
MIT							✓, for storage of loose contamination (in sealable container or plastic bag)	✓, also for cleaning of contami-nated parts of reactors or furnaces
NASA-ARC							✓	✓
NSF								
ORC Worldwide			✓, enclosing exhaust hood; if exterior exhaust hood: additional respiratory protection and close localisation to nanoparticle source			✓ with low velocity (e.g. Flow Sciences),	verify effectiveness before using. For example use a nanoscale particle counter to determine if particles escape from the containment.	
OUHSC-IBC								
Penn-EHRS								✓, particles, aerosoles
TU Delft						✓, HEPA-filtered		
UBC						✓, present, HEPA-		
UC						✓, HEPA-filtered, powered exhaust laminar flow hood		
UCI							✓	✓
UCSB							✓	✓
UD				✓			✓	
VCU								

1. Category S(pecific) nanomaterial guidelines (cont. Technical Measures)

Guideline documents \ Technical measures	extractor	ventilated fume hood	fume exhaust hood	closed fume hood	recirculating fume cupboard	ducted fume cupboard	ventilated hood with air flux	fume cupboards
AIST								
CHS								
DOE-NRSC								
EPFL							✓	
Georgia Tech			✓					
HSE-a								✓
ISU								
MIT								
NASA-ARC			✓					
NSF								
ORC Worldwide								
OUHSC-IBC								
Penn-EHRS								
TU Delft			✓	✓, HEPA-filtered				
UBC								
UC			✓, use to expel fumes from tube furnaces or chemical reaction vessels					
UCI			✓					
UCSB			✓					
UD								
VCU								

1. **Category S(pecific)** nanomaterial guidelines (cont. Technical Measures)

Guideline documents \ Technical measures	chemical fume hood	local capture hood / system	glove box	glove bag	downflow booth	chemical hood	exhaust system
AIST		Recommended enclose with benchtop fume hood, etc. with HEPA filter in case of handling category 4 (dust amount 1 g or less).	✓	✓			
CHS	✓, HEPA-filtered		✓, HEPA-filtered				
DOE-NRSC	✓		✓, negative pressure differential, exception: if precursor material has high air reactivity -> positive pressure (helium leak test)	✓, negative pressure differential		✓, laboratory bench-top or floor-mounted, negative pressure differential	✓
EPFL							
Georgia Tech							
HSE-a							
ISU	✓, here handling of dry nanoparticles or fumes / gases		✓, here handling of dry nanoparticles				
MIT			✓	✓, removal of particles from a reactor, connected to HEPA filter			
NASA-ARC							✓
NSF							
ORC Worldwide	✓		✓		no downflow booth, since it will not provide adequate protection without additional respiratory protection		
OUHSC-IBC	✓						
Penn-EHRS			✓, particles, aerosoles				
TU Delft			✓				✓
UBC							
UC							✓
UCI		✓, HEPA-filtered	✓, HEPA-filtered				
UCSB		✓, HEPA-filtered	✓, HEPA-filtered				✓
UD							
VCU	✓, in case of aerosol exposure						

1. Category S(pecific) nanomaterial guidelines (cont. Technical Measures)

Guideline documents \ Technical measures	exhaust air purification	exhaust ventilation system	exhaust ventilation	ventilation system	filtration system	ventilation	extraction facilities	specials, for instance extra barriers
AIST	High-efficiency filter is recommended. Use of electric dust collector, etc. may be considered if the targeted material can be collected properly.			Sufficient airflow control is recommended in relation to the central ventilation system.				
CHS						pass exhaust air through HEPA filter		
DOE-NRSC			✓	✓		✓		
EPFL						✓, 6mm of water column		
Georgia Tech								
HSE-a								
ISU								
MIT			✓, also removal of particles from a reactor					
NASA-ARC								if no fume hood is used, extra ventilation or barriers
NSF								
ORC Worldwide								
OUHSC-IBC								
Penn-EHRS				non-recirculating (preferably 100 % exhaust air), 6-12 air changes per hour, negative laboratory pressurization				
TU Delft								
UBC								
UC								evaluate emission controls on a case by case basis; test effectiveness of filtration by air sampling up- and downstream of HEPA filters
UCI								
UCSB								
UD		✓				✓		
VCU								

2. Category G(eneral) nanomaterial guidelines (cont. Technical Measures)

Guideline documents / Technical measures	technical measures general	safety equipment	closed system	LEV (local exhaust ventilation) / local exhaust system	clean room
BAuA / VCI	✓		✓		
Hallock et al., 2009	✓		✓, under vacuum or exhaust ventilation	✓, or vacuum for equipment which is too large for fume hood	
HMUELV	✓		✓		
Hoyt and Mason, 2008	✓		✓	✓	
HSE-b	✓			✓, HEPA-filtered, regular maintenance, testing once a year	
IRSST	✓		closed, leakproof enclosure	✓	
MHLW	✓		✓ glove box, enclosure, in principle, sealing, unmanning, and/or automation	local exhaust ventilation or push-pull type ventilation / HEPA filtered, access opening for maintenance and inspection of enclosures shall be equipped by LEV to enable a fully enclosure, direct the outlet of the LEV directly open to the outside air or connect the LEV to the existing exhaust duct	
NanoSafe Australia	✓				✓, for some processes
NIOSH	✓				
OSHA-EUROPA	✓		✓	✓	
PENNSTATE	✓		✓, under vacuum or exhaust ventilation		
Safe Work Australia	✓		✓	✓	
Schulte et al., 2008	✓				
Surrey-ATI	✓			✓, HEPA-filtered	

2. Category G(eneral) nanomaterial guidelines (cont. Technical Measures)

Guideline documents \ Technical measures	sterile cabinet	biohazard cabinet	microbiological safety cabinet	biological safety cabinet / biosafety cabinet	reactor	furnace	ventilated cabinet	dust collection system
BAuA / VCI								
Hallock et al., 2009				✓	✓, exhaust gases, purge before opening, provide LEV for emission points, maintain party in fume hood	✓, exhaust gases, purge before opening, provide LEV for emission points, maintain party in fume hood		
HMUELV								
Hoyt and Mason, 2008								
HSE-b			class II or III, i.e. HEPA-filtered	Recirculating biological or safety cabinets are unsuitable, because they do not sufficiently control exposure				
IRSST								
MHLW								
NanoSafe Australia	✓, for some processes certified by NATA, test efficiency annualy	✓, HEPA-filtered certified by NATA, test efficiency annualy		✓, HEPA-filtered, class II is sufficient, certified by NATA, test efficiency annualy				
NIOSH								
OSHA-EUROPA								
PENNSTATE								
Safe Work Australia								
Schulte et al., 2008								
Surrey-ATI								

2. Category G(eneral) nanomaterial guidelines (cont. Technical Measures)

Technical measures / Guideline documents	dust hood	local exhaust source	local exhaust	dedicated exhaust duct	exhaust hood	source enclosure	laminar flow cabinet	laminar flow hood	hood
BAuA / VCI									
Hallock et al., 2009									✓, collection of loosly contaminated materials like wipes or PPE
HMUELV			✓						
Hoyt and Mason, 2008								✓	verify effectiveness of air flow before using any hood, smoke tubes provide a good visualisation of air flow
HSE-b									
IRSST									
MHLW									
NanoSafe Australia							not recommended, since they blow contaminated air towards the operator		
NIOSH									
OSHA-EUROPA									
PENNSTATE									
Safe Work Australia									
Schulte et al., 2008									
Surrey-ATI									

2. Category G(eneral) nanomaterial guidelines (cont. Technical Measures)

Technical measures / Guideline documents	fume hood	extractor	ventilated fume hood	fume exhaust hood	closed fume hood	recirculating fume cupboard	ducted fume cupboard	ventilated hood with air flux	fume cupboards
BAuA / VCI		✓, required according to TRGS 526							
Hallock et al., 2009	✓								
HMUELV	✓, requirements according to TRGS 526								
Hoyt and Mason, 2008									
HSE-b						✓, conform to BS 7989:2001	✓, HEPA-filtered, shall comply with BS EN 14175-4:2003		
IRSST									
MHLW									
NanoSafe Australia	✓, HEPA-filtered, certified by NATA, test efficiency annualy								
NIOSH									
OSHA-EUROPA		fume extractor, HEPA-filtered							
PENNSTATE	✓, processing particles		✓, synthesis of particles						
Safe Work Australia	✓	✓							
Schulte et al., 2008									
Surrey-ATI	✓								

2. Category G(eneral) nanomaterial guidelines (cont. Technical Measures)

Guideline documents \ Technical measures	chemical fume hood	local capture hood / system	glove box	glove bag	downflow booth	chemical hood	exhaust system	exhaust air purification	exhaust ventilation system
BAuA / VCI								✓, recirculate air with exhaust air purification	
Hallock et al., 2009			✓						
HMUELV								✓	
Hoyt and Mason, 2008	✓		✓						
HSE-b									
IRSST									
MHLW			✓						
NanoSafe Australia									
NIOSH									
OSHA-EUROPA									
PENNSTATE	✓	✓, dosing and necropsy of exposed animals	✓, synthesis of particles, HEPA-filtered						
Safe Work Australia								✓	
Schulte et al., 2008									
Surrey-ATI									

2. Category G(eneral) nanomaterial guidelines (cont. Technical Measures)

Technical measures / Guideline documents	exhaust ventilation	ventilation system	filtration system	ventilation	extraction facilities	specials, for instance extra barriers
BAuA / VCI					✓, regular maintenance and function testing	capture, limit and remove dangerous gases vapours and dusts at source, if possible
Hallock et al., 2009	✓					
HMUELV						
Hoyt and Mason, 2008						
HSE-b						
IRSST				with HEPA or ULPA filters		
MHLW						
NanoSafe Australia						
NIOSH						
OSHA-EUROPA		✓	✓, with multistage filters and HEPA- or ULPA-filter as final filter according to EN 1822-1 to EN 1822-5	✓		
PENNSTATE	✓					
Safe Work Australia		✓, HEPA-filtered or with electrostatic precipitation	✓	✓	✓	
Schulte et al., 2008		✓, HEPA-filtered				
Surrey-ATI						HEPA filters should be contained in a suitable filter housing

3. Category L(aboratories) guidelines (cont. Technical Measures)

There are only 2 technical measures mentioned by the 2 guidelines.

Technical measures / Guideline documents	technical measures general	fume hood
AGS-BMAS	✓	✓, or adequate protection level
DGUV	✓	

ANNEX VIII. Organisational Measures

The need for organizational measures is emphasized in a number of nanomaterial guidelines applicable for laboratories to reduce the potential exposure.

1. Category S(pecific) nanomaterial guidelines

guideline documents	organizational measures generally
AIST	Isolate the areas potential for exposure to nanomaterials (handling category 4 and higher) from other areas. (1) Physically separate office from laboratory potential for exposure to nanomaterials. (2) If possible, separate the same laboratory into the areas potential for exposure and the area not susceptible to exposure. (3) Establish an area in which work clothing and protective wears/equipment can be stored and a changing room (4) Install hand-wash and eye-wash station near the changing room. (5) Treat nanomaterial adhered work clothing, etc. appropriately to prevent the nanomaterials from spreading beyond the workplace. Do not keep work clothing together with other clothing in a same locker. (6) Restrict the entrance of an unauthorized person to the area potential for exposure to nanomaterials.
CHS	✓, special area for non-disposable laboratory coats, responsible: health and safety office
DOE-NRSC	✓, change out area for clothes,
EPFL	✓, responsible person: project manager, security agent, control access zone with entrance area, list of employees, no storage of nanoparticles in offices or hallway, change of clothes, stable depression in work area, no storage of food in working area, eating, drinking, smoking, and storage of cosmetic products not allowed, no pipetting with mouth, working zone: "dangerous nanoparticles"
Georgia Tech	✓, consult health and safety office before initiation of project
HSE-a	✓, working procedures, supervision
ISU	
MIT	
NASA-ARC	✓, storage of carbon nanopowder in sealed containers, more than 1 g: storage in metal containers (avoid electrostatic discharge), no eating or drinking
NSF	
ORC Worldwide	✓, consult health and safety office
OUHSC-IBC	handwashing facilities, safe needle device for administration of nanomaterials using needles/syringes, usage of needle-locking or disposable syringes
Penn-EHRS	✓, hand washing facilities
TU Delft	✓, monitor air with nanoparticle detector if gas phase work is performed and more than 1 µg/h of a nanomaterial is produced: (instruments: "Joint Length Monitor" or "Delf ChemTech")
UBC	✓, no work alone, outside normal working hours: in pairs for dangerous works, another person in building for less-dangerous works, user list at the entrance, room for cloth change, login required, cleanroom: closed at night, telefon inside, smoking prohibited, cleanroom manager, record equipment time usage
UC	✓, eating and drinking prohibited
UCI	✓, eating, drinking and chewing gum prohibited
UCSB	✓, eating, drinking and chewing gum prohibited
UD	✓, access controls, designed area for clothes, facilities for showering or changing, food in work area prohibited
VCU	

2. Category G(eneral) nanomaterial guidelines

guideline documents	organizational measures generally
BAuA / VCI	
Hallock et al., 2009	
HMUELV	✓, washing facilities, hygiene measures, separate storage of clothes, rules for acces and storage, supervision
Hoyt and Mason, 2008	
HSE-b	supervision, access control to working area
IRSST	prohibition of smoking, drinking, eating or applying makeup in the work areas, minimization of the number of workers, access limited, standardization of all work surfaces, washbasins and showers
MHLW	operation rules, cleaning floors and work benches by wiping with wet clothes, separation of work area, hand washing, storage of waste and used PPE, rules for access, keeping of operation records, the employer shall establish measures to be taken in case of incident or accident in advance, such as alarms, notification to other workers, or exposure preventive measures at a time when a large spill takes place
NanoSafe Australia	✓, change rooms, laundry service
NIOSH	✓
OSHA-EUROPA	✓
PENNSTATE	✓, eating, drinking and cosmetic application prohibited, laboratory coats shall not be worn outside the laboratory, review of protocol by health and safety office
Safe Work Australia	✓, limit access to areas, reduce time spent in possible exposure areas (e.g. hot areas), reduce number of personel potentially exposed, storage of PPE separately from private clothing
Schulte et al., 2008	✓
Surrey-ATI	✓, storage and consumption of food prohibited, hand washing facilities

3. Category L(aboratories) guidelines

guideline documents	organizational measures generally
AGS-BMAS	✓
DGUV	✓

VIII-1. Labelling

Upon the precautionary approach, labelling is required regarding the in-company handling of nanomaterials, which is described in the several guidelines.

1. Category S(pecific) nanomaterial guidelines

guideline documents	labelling		
	general	area	storage
AIST			
CHS	✓	label HEPA vacuum cleaner with the sign “For Use with Nanoparticles Only”	
DOE-NRSC	✓	post signs indicating hazards, PPE requirements and administrativ control requirements at entry points into designated areas, where dispersible, engineered nanomaterials are handled. A designated area may be an entire laboratory, an area of a laboratory or a containment device such as a laboratory hood or glove box.	label storage containers to indicate that the contents are in engineered nanoparticulate form, e.g. "nanoscale zinc oxide particles" or other identifier instead of just "zinc oxide"
EPFL			
Georgia Tech			
HSE-a			
ISU			
MIT	✓	in areas, where easily dispersible nanoparticles are in use, post signs shall indicate the hazards, control procedures, and PPE that is required. If warranted, use the Chemical Hygiene Plan "Designated Area" sign available from the EHS office to label the fume hood, laboratory bench, or laboratory itself.	Nanomaterial storage containers should have a designation that the material is "nanoscale" or a "nanomaterial", such as "nanoscale titanium dioxie".
NASA-ARC			
NSF			
ORC Worldwide			
OUHSC-IBC			
Penn-EHRS			
TU Delft			
UBC	✓		
UC			
UCI			
UCSB			
UD			
VCU			

1. Category S(pecific) nanomaterial guidelines (cont. Labelling)

guideline documents	transport	waste	unspecific	explanatory notes
AIST				
CHS	internal transport between work stations: in closed labelled containers			containers: CAUTION - Nanomaterials Sample - Consisting of (technical description here) Contact: (POC) at (contact number) in Case of Container Breakage
DOE-NRSC	internal transport between work stations: in closed, labelled containers, e.g. marked "Zip-Lock" bags; when nanomaterials are being moved outside, include label text that indicates that the particulates might be unusually reactive and vary in toxic potential, quantitatively and qualitatively, from normal size forms of the same material external transport: nanomaterials with suspected or recognized hazardous properties (toxic, reactive flammable) must be packaged, marked, labeled and shipped in accordance with 49 CFR 100 to 185 and applicable DOE Orders with an accompanying properly prepared dangerous goods declaration, in accordance with the ICAO technical instructions; unknown nanomaterials still may pose health and safety issues: therefore they shall be consistently packaged using the equivalent of a DOT-certified Packing Group I (PG I) container and labeled	label the waste container with a description of the waste and the words "contains nanomaterials". Include available information characterizing known and suspected properties		for transport: CAUTION - Nanomaterials Sample - Consisting of (technical description here) Contact: (POC) at (contact number) in Case of Container Breakage
EPFL				
Georgia Tech				
HSE-a				
ISU				
MIT		Nanomaterial waste management: Label the outer bag /container with the hazardous red tag. The content section of the label must indicate that it contains nano sized particles and indicate what they are.		
NASA-ARC				
NSF				
ORC Worldwide				
OUHSC-IBC				
Penn-EHRS				
TU Delft				
UBC				
UC				
UCI				
UCSB				
UD				
VCU				

2. Category G(eneral) nanomaterial guidelines (cont. Labelling)

guideline documents	labelling						
	general	area	storage	transport	waste	unspecific	explanatory notes
BAuA / VCI							
Hallock et al., 2009	✓						
HMUELV							
Hoyt and Mason, 2008							
HSE-b							
IRSST							
MHLW	✓					container or package: name and components of and precautions for handling such nanomaterials	
NanoSafe Australia							
NIOSH	✓						
OSHA-EUROPA	✓					deviating properties of a nanomaterial can be identified by classification and labelling	
PENNSTATE	✓					✓, consistent with existing laboratory requirements	
Safe Work Australia	✓						
Surrey-ATI							
Schulte et al., 2008							

3. Category L(aboratories) guidelines (cont. Labelling)

guideline documents	labelling						
	general	area	storage	transport	waste	unspecific	explanatory notes
AGS-BMAS	✓						
DGUV	✓						

VIII-2. Personal Training

Under the framework of the organisational measures, a broad range of possibilities for information and training of the workers who are potentially exposed to nanomaterials are addressed in the several guidelines.

1. Category S(pecific) nanomaterial guidelines

guideline documents	personal training
AIST	The person responsible for the work handling nanomaterials shall establish a manual for the handling procedures, etc. and educate the workers well and have them comply with the handling procedures specified in the manual. Inform the workers of the risk associated with the handlings of nanomaterials.
CHS	annual training
DOE-NRSC	training course: usage of PPE, handling of contaminated clothes or surfaces, disposal of spilled nanomaterials, employing engineering controls
EPFL	technical and practical advice, training of the employees in collaboration with the project managers
Georgia Tech	
HSE-a	training, information, involvement of the workers in the design and implementation of control measures
ISU	
MIT	
NASA-ARC	safety training classes, laboratory safety plan, standard operating procedures (SOP), for some procedures Job Hazard Analysis Worksheet (JHA), mentoring when setting up new equipment
NSF	chemical and materials hygiene program; educational program in environ-mental, health and safety; information of procedures for handling and disposal of nanomaterials, workshops
ORC Worldwide	
OUHSC-IBC	
Penn-EHRS	
TU Delft	
UBC	regular workers: chemical and laboratory safety orientation course, qualification course on individual equipment, students: additionally chaperoned by qualified user, visitors: supplementary agreement with clean room manager
UC	
UCI	brief exposed workers, written report on participants
UCSB	brief exposed workers, written report on participants
UD	regular information
VCU	training:specific nanoparticle-related health and safety risks, SOP, instructions to perform injections involving nanoparticles, VCU Laboratory Safety Training Modules; respiratory protection program of the university that meets OSHA's 29 CFR 1910.134 and ANSI Z88.2 requirements

2. Category G(eneral) nanomaterial guidelines

guideline documents	personal training
BAuA / VCI	
Hallock et al., 2009	chemical hygiene plan
HMUELV	training, education
Hoyt and Mason, 2008	
HSE-b	training and information on controlling exposure
IRSST	programs to inform and train workers
MHLW	operation rules,physical and chemical properties of nanomaterials, health effects of nanomaterials, control measures for the work environment, instructions concerning the following: proper selection of RPE; method on how to put on the RPE; the measurement method of leakage based on the adequacy of fit between the face piece of respirators and the face; method of fit test; and storage and maintenance of RPE, measures of preventing fire and explosion
NanoSafe Australia	
NIOSH	✓
OSHA-EUROPA	
PENNSTATE	
Safe Work Australia	personnel training, information provision about special measures for handling engineered nanomaterials and the possibility of negative health effects, information in operating instructions
Schulte et al., 2008	
Surrey-ATI	

3. Category L(aboratories) guidelines

guideline documents	personal training
AGS-BMAS	✓
DGUV	✓

VIII-3. Cleaning

The aspect of cleaning is an essential issue mentioned in the predominant number of nanomaterial guidelines for laboratories.

1. **Category S(pecific)** nanomaterial guidelines

guideline documents	cleaning generally	routine cleaning
AIST	✓	Use wet wipe or vacuum cleaner when cleaning up Vacuum cleaner shall be equipped with HEPA filter, etc. having a function that prevents nanomaterials from dispersing with the exhaust air. Do not use air spray.
CHS	✓	clean all potentially contaminated working surfaces at the end of each day, use HEPA vacuum (labelled "for use with nanoparticles only") or wet wiping methods, do not dry sweep or use compressed air, a benchtop protective covering material, which is disposed daily can be used instead of vacuuming
DOE-NRSC	✓	wet-wiping surfaces with a moistened disposable wipe at the end of each shift, consider complications due to chemical and physical properties, walk-off mats, HEPA-filtered vacuum, wet-wiping, consider air-reactivity of powders, prohibited: dry sweeping or use of compressed air
EPFL	✓	work places have to be cleaned after work, regular cleaning by the person in charge of the laboratory
Georgia Tech	✓	
HSE-a		
ISU	✓	use amended water or another cleaning agent, which is compatible, avoid solvents, wear additionally half-face respirator with P100 filter during HEPA-filtered vacuuming
MIT	✓	✓
NASA-ARC	✓	wet-wipe surfaces (at least weekly, with spraybottles and laboratory wipes), with water or other solvents prior to intended use, clean water sensitive instrument surfaces with electrostatic microfiber cleaning cloths, dispose cleaning cloths (drying prohibited), dry sweeping, vacuuming or the use of compressed air are prohibited unless precautions are taken to trapp particles by HEPA filters
NSF		
ORC Worldwide	✓	
OUHSC-IBC	✓	disposable bench covers for solutions containing nanoparticles, clean surface with cleaning solution (suitable for the type of nanomaterial)
Penn-EHRS	✓	daily, HEPA-filtered vacuum, use cleaning solution after each work activity (link: CONTRAD® 70)
TU Delft	✓	clean with HEPA-filtered vacuum cleaner
UBC	✓	walk-off mats, wipe with cleanroom wipes and iso-propanol
UC	✓	
UCI	✓	wet wipe, vacuum or use disposable bench paper, daily cleaning
UCSB	✓	wet wipe, HEPA-filtered vacuum, walk-off mats
UD	✓	after each work shift: HEPA vacuum, wet wiping methods
VCU	✓	use bench paper with impervious backing to limit potential for contamination of surfaces, clean immediately after each task

1. Category S(pecific) nanomaterial guidelines (cont. Cleaning)

guideline documents	cleaning / hygiene employees	cleaning in case of contamination
AIST		At the time of an irregular or emergency cleaning up of spilled samples, etc. extra cautious preventive measures against exposure should be taken because the potential risk for exposure is higher in such cases. The irregular or emergency work shall be recorded and the record be retained.
CHS		demarcate contaminated area with barricade tape, contact EHS office, smaller spills: cleaned up by trained personnel: walk-off mats at exit of area, clean with wet wipes; significant spills: vacuum with HEPA-filtered vacuum cleaners under direction of health and safety office; liquids: walk-off mat, barriers that will minimize air currents, HEPA filtered vacuum; nanomaterial spill kit: barricade tape, latex or nitrile gloves, disposable N95 respirators, absorbent material, wipes, sealable plastic bags, walk-off mat
DOE-NRSC	wash hands and forearms after wearing gloves dispose contaminated clothes	consider pyrophoric hazards associated with vacuuming nanomaterials clean and dispose contaminated clothes according to laboratory procedures, walk-off mats, HEPA-filtered vacuum, wet wiping; prohibited: dry sweeping or use of compressed air, larger spills: demarcate area with barricade tape, entry to laboratory shall be restricted to laboratory waste management crew
EPFL	wash hands before any procedure and before leaving the laboratory	close and decontaminate the contaminated zone
Georgia Tech	wash hands before leaving the laboratory	either HEPA-filtered vacuum or call health and safety office
HSE-a		
ISU	wash hands after the use of a nanomaterial, contaminated clothes shall be laundered or disposed, if potential for contamination: wear disposable coveralls and boots	
MIT	wash hands and forearms throughly after handling nanomaterials	minor spills: wet wiping for solid material, absorbent wipes for suspensions, larger spills: HEPA filtered vacuum cleaner nanoparticle spill kit: barricade tape, nitrile gloves, disposable P100 respirators, absorbent material, wipes, sealable plastic bags, walk-off mats contaminated material: repair or clean in a fume hood or other type of exhausted enclosure, exception: too large material in specially designed local exhaust ventilation
NASA-ARC		very small spills of carbon particles: absorption of suspensions with cleaning cloths or Kimwipes, clean suspensions immediatly before they dry, damp cleaning for powders: spray with a water mist, then wipe clean; larger spills (e.g. cleaned in more than 5 min): either leave area or use PPE (respirator and disposable protective closing) and comply with requirements for emergency response by hazardous materials users; spills beyond capability of laboratory: call emergency telephone number, only a designated hazardous material emergency response team is permitted to enter the affected area; contaminated material: spill kit for carbon-based nanomaterials: spray bottles containing water and disposable wipes
NSF		
ORC Worldwide		small spills of powder: wipe carefully with wet paper towels or cloths
OUHSC-IBC		
Penn-EHRS	hand washing after handling nano materials	HEPA vacuum cleaner, dry sweeping prohibited
TU Delft		HEPA-filtered vacuum cleaner, wetwiping, use dampened cloths to wipe up powders, apply absorbent materials/liquid traps, use PPE contaminated material: clean all exposed reaction vessels in a fume hood: vacuum cleaner with HEPA filter, wipe with wet cloth
UBC	separate storage of working garment, suits shall be changed 1x a workweek	
UC		HEPA-filtered vacuum cleaners
UCI		wet wipe or vacuum, wear double nitrile gloves, particles: respiratory protection, brushing or sweeping prohibited, walk-off mats
UCSB		double nitrile gloves, HEPA-filtered vacuum or wet wipe with towels, walk-off mats, particles: respiratory protection, contact health and safety office, brushing or sweeping prohibited
UD	wash hands prior to eating, smoking or leaving the worksite	
VCU	wash hands with soap and water before and immediately upon removal of gloves, contaminated clothes have to be changed promptly	small spills of powder (<5mg): wetwipe with cloth dampened in soaped water small spills of solution (<5ml): absorbent material affected areas: wet-wipe 3times with soap and water or appropriative cleaning agent large spills: contact OEHS emergency line

2. Category G(eneral) nanomaterial guidelines (cont. Cleaning)

guideline documents	cleaning generally	routine cleaning	cleaning / hygiene employees	cleaning in case of contamination
BAuA / VCI				
Hallock et al., 2009	✓	wet wipe daily, HEPA vacuum cleaner, no sweeping or usage of compressed air		wet wiping (small spills), HEPA vacuum cleaner (large spills), appropriate absorbent
HMUELV	✓	vaccuuming, wet wiping		
Hoyt and Mason, 2008				
HSE-b	✓			
IRSST	✓	wet-wiping, vacuum cleaner with HEPA filter, cleaning at least once a shift, explosion-proof in case of explosive nanoparticles. This vacuum cleaner can be designed with insulating materials, a ground or an explosion vent to prevent production of ignition sources, i.e. sparks or static electricity. Another option is to use an electrical mobile vacuum cleaning system with an induction motor to avoid sparks.	✓	
MHLW	✓	vacuum cleaners with HEPA filters, wipe with wet cloths	wash the exposed or possibly exposed skin with soap, or wipe off the skin with a cleansing cream	perform dust removal in a clean-air environment, if eye contact occurs, wash eyes thoroughly with water; if inhaled, gargle or rinse mouth; and if swallowed, spit it out, gargle and wash rinse mouth
NanoSafe Australia	✓	HEPA-filtered vacuum cleaner that comply with Australian standards AS 3544-1988 (industrial vacuum cleaners for particulates hazardous to health, NO household vacuum cleaners) and AS 4260-1997 HEPA, wet wiping	do not take contaminated clothing home	
NIOSH	✓			
OSHA-EUROPA	---			
PENNSTATE	✓	wet-wiping, HEPA vacuuming, prohibited: dry sweeping or using compressed air	wash hands before leaving area and after removing protective gloves, avoid touching skin before washing hands, do not take contaminated clothing home	minimize production of aerosols, wet wiping (larger spills: after collection of bulk material), HEPA-filtered vacuum cleaner, prohibited: dry sweeping, larger spills: respirator with HEPA filter
Safe Work Australia	✓	on a regular basis, vacuum cleaner with HEPA filter, wet wipes		
Schulte et al., 2008				
Surrey-ATI	✓	clean daily with HEPA-filtered vacuum cleaner, prohibited: dry sweeping and pressurised gas hose	wash hands before leaving the work area	HEPA-filtered vacuum cleaner, wet wiping, apply absorbent material, dispose cleaning materials, vacuum cleaner design should avoid electrostatic charge by neutralising any charges

3. Category L(aboratories) guidelines (cont. Cleaning **)**

guideline documents	cleaning generally	routine cleaning	cleaning / hygiene employees	cleaning in case of contamination
AGS-BMAS	✓			
DGUV	✓			

ANNEX IX. Personal Protective Equipment

The general application of appropriate personal protective equipment (PPE) while handling nanomaterials, which supplements organizational and engineering measures, is recommended by a number of guidelines.

1. **Category S(pecific)** nanomaterial guidelines

	PPE	Respiratory protection		
guideline documents				
	general	general	filter	type of mask
AIST		✓		High-efficiency mask
CHS	✓	✓	P100 for half mask or N95 for disposable mask	appropriate respirator and cartridge combination (based on EHS analysis) according to safety assessment; half-mask or disposable respirator (i.e. dust mask, NO surgical mask)
DOE-NRSC	✓	✓	P100 or better	half-mask
EPFL	✓	✓		
Georgia Tech	✓	✓		
HSE-a	✓	✓	check with manufactured, depends on type and size of particle	in cases of high load, i.e. high concentration or missing information breathing apparatus (full-face mask with compressed air supply) provided clean air of independent source
MIT	✓	✓	P100	
NASA-ARC	✓	✓	N95 or better	disposable mask or better
NSF	✓	✓		
ORC Worldwide	✓	✓	P100/P3/HEPA	PAPR (powered air-purifying respirator) in enclosed system, or an air-supplying respirator outside of an enclosed system
OUHSC-IBC		✓		respirator
Penn-EHRS	✓	✓		
TU Delft	✓	✓	FFP3 or P3	selection based on professional consultation
UBC	✓			
UC	✓			
UCI	✓	✓	NIOSH approved N-,R- oder P-100 (HEPA)	
UCSB	✓	✓	NIOSH approved N-,R- oder P-100 (HEPA)	
UD		✓	P-100	
ISU	✓	✓	P100	half-mask
VCU	✓			

1. Category S(pecific) nanomaterial guidelines (cont. Personal Protective Equipment)

	gloves			
guideline documents				
	general	type	double?	specifics
AIST	✓	Impermeable gloves		
CHS	✓	latex or nitril		change frequently
DOE-NRSC	✓	nitrile, consider suitability to material		gauntlet-type or extended sleeves
EPFL	✓			
Georgia Tech	✓			
HSE-a				
MIT	✓	nitrile	double gloves in case of	with gautlets of extended
NASA-ARC	✓	nitrile		
NSF	✓			
ORC Worldwide	✓	nitrile recommended, but this depends upon chemistry of the material		gloves should always be removed inside the hood
OUHSC-IBC	✓			cover wrist and exposed skin of arm
Penn-EHRS	✓	nitrile		disposable
TU Delft	✓		✓, minimum two layers	
UBC	✓	nitrile, latex or triple-polymer		suitable material depends on particular application
UC	✓			
UCI	✓	nitrile	✓	
UCSB	✓	nitrile	✓	
UD	✓	latex or nitrile		
ISU	✓	nitrile	✓	place over end of laboratory coat sleeve
VCU	✓	nitrile or latex	recommended	shall cover hand and wrist completely, overlap sleeve of laboratory coat

1. Category S(pecific) nanomaterial guidelines (cont. Personal Protective Equipment)

guideline documents	eye protection general	eye protection specifics	closed-toed shoes
AIST	✓	Protective eyewear, Airtight eyewear, goggle-type protection glasses	Shoes covering the whole feet (work
CHS	✓	safety glasses and/or face shields appropriate for the level of hazard	✓, made of low-permeability material, + disposable over-the-shoe-booties
DOE-NRSC	✓	safety glasses with side shields, face shields or chemical splash google	made of low per-meability material, over-the-shoe booties
EPFL	✓	glasses	over shoes
Georgia Tech	✓	safety glasses, face shield	✓
HSE-a			
MIT	✓	safety glasses, googles or face shields	
NASA-ARC	✓	safety glasses	✓
NSF			
ORC Worldwide			
OUHSC-IBC	✓	safety glasses or googles	
Penn-EHRS	✓	safety glasses	✓
TU Delft	✓	safety glasses, face shield	✓
UBC	✓	safety glasses, at the "wetbench" splash googles or full facial protection	✓, shoe covers
UC	✓	safety glasses, face shields	✓
UCI	✓	safety glasses or googles	
UCSB			
UD	✓		
ISU	✓	safety googles	✓
VCU	✓	safety glasses (ANSI Z-87 approved); full-face shield when conducting tasks with generation of aerosoles or droplets	✓

1. Category S(pecific) nanomaterial guidelines (cont. Personal Protective Equipment)

guideline documents	laboratory coat or overall			further recommendations for PPE	
	general	material	specifics	general	specifics
AIST	✓		Impermeable protective clothing		Regardless of using protective equipment or not, make sure to cover and protect wounds or lesions on skin, and dermatological diseases. Do not take out PPE from the laboratory after using. The PPE should be cleaned carefully and thoroughly in order to avoid secondary contamination.
CHS	laboratory coat		disposable; non-disposable should remain in the laboratory area		long pants without cuffs, long-sleeved shirt
DOE-NRSC	laboratory coat			✓	long pants without cuffs, long-sleeved shirt
EPFL	✓	overall or long sleeved shirts with buttons on the back			
Georgia Tech	laboratory coat				
HSE-a					
MIT	laboratory coat				
NASA-ARC	laboratory coat				
NSF					apron
ORC Worldwide					
OUHSC-IBC	laboratory coat				arm sleeves
Penn-EHRS	laboratory coat			✓	long pants, arm sleeves
TU Delft	laboratory coat				
UBC	coverall	plastic		✓	hair cover, beard cover
UC	laboratory coat				
UCI	laboratory coat				
UCSB	✓				
UD	✓	Tyvek overall			
ISU	laboratory coat				
VCU	laboratory coat or disposable coverall			✓	no short pants or dresses

2. Category G(eneral) nanomaterial guidelines (cont. Personal Protective Equipment)

guideline documents	gloves			
	general	type	double?	specifics
BAuA / VCI	✓			suitable material
Hallock et al., 2009	✓	nitrile	if extensive skin contact	extended sleeves if extensive
HMUELV				
Hoyt and Mason, 2008	✓	nitrile		
HSE-b	✓	disposable, if latex: low protein powder-free gloves		
IRSST	✓			according to permeability to the solvent used
MHLW	✓	use protective gloves made of appropriate materials, disposable.		
NanoSafe Australia	✓	nitrile, polypropylene, latex	✓, made from different materials	changed regularly during the day
NIOSH				
OSHA-EUROPA	✓	nitrile, latex, neoprene		
PENNSTATE	✓	nitrile in case of intensive skin contact	two pairs of gloves in case of intensive skin contact	sturdy, good chemical resistance, solvent resistent properties
Safe Work Australia	✓	when handling liquids: nitrile with extended sleeves	✓	glove management system: maintenance, storage, removal, disposal, training, ergonomics, material selection and the exposure/task scenario; Choose glove after considering the resistance to chemical attack of both nanomaterial and liquid
Schulte et al., 2008				
Surrey-ATI	✓	disposable powder free gloves		

2. Category G(eneral) nanomaterial guidelines (cont. Personal Protective Equipment)

guideline documents	eye protection		closed-toed shoes
	general	specifics	
BAuA / VCI	✓	protective googles with side protection	
Hallock et al., 2009			
HMUELV			
Hoyt and Mason, 2008			
HSE-b			
IRSST	✓		shoe covers
MHLW	✓	goggle-type	
NanoSafe Australia			✓, disposable shoe covers or neoprene shoes
NIOSH			
OSHA-EUROPA			
PENNSTATE			
Safe Work Australia	✓	protective googles with side-protection	
Schulte et al., 2008			
Surrey-ATI	✓	googles	

2. Category G(eneral) nanomaterial guidelines (cont. Personal Protective Equipment)

guideline documents	laboratory coat or overall			further recommendations for PPE	
	general	material	specifics	general	specifics
BAuA / VCI	protective clothing				
Hallock et al., 2009	laboratory coat	preferable disposable			
HMUELV					full body protection
Hoyt and Mason, 2008					
HSE-b	✓	no wool, cotton or knitted material, should not retain dust			
IRSST	coverall or laboratory coat				
MHLW		unwoven cloth, effective and clean conditions shall be maintained			
NanoSafe Australia	Overall 1 Overall 2	fabric overall Tyvek or polypropylene	overall (2) over overall (1)		protective closing should cover all areas of skin
NIOSH					
OSHA-EUROPA	✓	Tyvex (polyethylene textile), no cotton			
PENNSTATE	laboratory coat				
Safe Work Australia	✓	unwoven cloth, i.e. Tyvex			
Schulte et al., 2008					
Surrey-ATI	laboratory coat				

3. Category L(aboratories) guidelines (cont. Personal Protective Equipment)

There are only 2 general guidelines mentioned Personal Protective Equipment.

guideline documents	PPE	Respiratory protection		
	general	general	filter	type of mask
AGS-BMAS	✓			
DGUV	✓			

ANNEX X. Medical Surveillance

A variety of view on the medical surveillance is presented in several guidelines regarding the issue of health of the exposed personnel.

1. Category S(pecific) nanomaterial guidelines

guideline documents	medical surveillance
AIST	If handling nanomaterials that fall under the category of substances applicable to one of the existing special medical examinations, receive the special medical examination concerned. First aid: 1) get into the eye: flush and rinse with plenty of water 2) Inhaled: gargle, wash and rinse the mouth thoroughly. Move to the clean air area 3) Ingested: If possible, spit out. Gargle, wash and rinse the mouth thoroughly. 4) Adhered to the skin: Wash with soap or wipe off with cleansing cream.
CHS	medical clearance by medical doctor before being fitted with respirator
DOE-NRSC	medical director: health monitoring program, routine tests such as pulmonary, renal, liver and hematopoetic functions
EPFL	if necessary (determined by project manager)
Georgia Tech	workers should be alert for the onset of symptomes associated with chronic effects
HSE-a	potentially health monitoring to detect health effects at an early stage and reduced the likelihood of long-term harm
ISU	
MIT	
NASA-ARC	
NSF	
ORC Worldwide	
OUHSC-IBC	
Penn-EHRS	
TU Delft	
UBC	
UC	pregnancy contraindication, granulomatous lung disease, higher hazard of allergenic or carcinogenic particles, potential routes of exposure, biological monitoring of blood and urine for nanoparticles
UCI	
UCSB	
UD	health monitoring when appropriate
VCU	

2. Category G(eneral) nanomaterial guidelines

guideline documents	medical surveillance
BAuA / VCI	
Hallock et al., 2009	
HMUELV	
Hoyt and Mason, 2008	
HSE-b	
IRSST	
MHLW	regular health examinations under the Industrial Safety and Health Law or the Pneumoconiosis Law, recognition of the latest health conditions of the worker
NanoSafe Australia	
NIOSH	✓
OSHA-EUROPA	general medical screening
PENNSTATE	respiratory protection program including physical evaluation and respirator fit testing, annualy
Safe Work Australia	Several potential disease outcomes: the acute and chronic immune system responses of inflammation, allergy and autoimmunity to viral-sized monodispersed nanoparticles and their bacterial-sized aggregates, respiratory, skin and gastrointestinal related disorders (e.g. liver dysfunction following sequestration of circulating particulates), neurological disorders as well as the potential for cancer of several different types due to oxidative damage to DNA and the tumour promoting events of chronic inflammation and wound repair from ongoing tissue damage, Routine medical and health surveillance
Schulte et al., 2008	medical screening, occupational health surveillance
Surrey-ATI	

3. Category L(aboratories) guidelines

guideline documents	medical surveillance
AGS-BMAS	✓
DGUV	✓

ANNEX XI. Transport

Several nanomaterial guidelines for laboratories suggest that nanoscaled materials should be transported following the adequate safety measures.

1. Category S(pecific) nanomaterial guidelines

guideline documents	transport
AIST	Transport and storage of nanomaterials shall be in a container or package that can safely enclose the materials and prevent exposure. Also, adequate safety measures equivalent to the measures for chemical materials shall be applied to protect the container or package from damages due to earthquake and fire.
CHS	closed, labeled containers
DOE-NRSC	in closed, labeled containes, e. g. marked 'Zip-Lock' bags, according to 49 CFR 100-185 and (if shipped by air) and according to ICAO*; outer package: shock and liquid absorbing material (definition PG 1), add description of material (MSDS), innermost container labeled, additionally: the driver must possess basic hazard information, the vehicle must have a valid state safety inspection
EPFL	
Georgia Tech	
HSE-a	
ISU	in sealed, labeled containers
MIT	in sealed containers
NASA-ARC	
NSF	
ORC Worldwide	
OUHSC-IBC	in closed containers
Penn-EHRS	transport dry nanoparticles in closed containers
TU Delft	like normal chemicals, i. e. use closed containers
UBC	
UC	according to hazardous chemical waste guidelines
UCI	
UCSB	
UD	
VCU	

2. Category G(eneral) nanomaterial guidelines

guideline documents	transport
BAuA / VCI	
Hallock et al., 2009	sealed container
HMUELV	
Hoyt and Mason, 2008	
HSE-b	
IRSST	
MHLW	
NanoSafe Australia	
NIOSH	✓
OSHA-EUROPA	
PENNSTATE	
Safe Work Australia	✓
Schulte et al., 2008	
Surrey-ATI	

3. Category L(aboratories) guidelines

guideline documents	transport
AGS-BMAS	✓
DGUV	✓

ANNEX XII. Waste Disposal

A number of nanomaterial guidelines applicable to laboratories suggest the disposal treatment of nanomaterials as chemical or hazardous waste.

1. Category S(pecific) nanomaterial guidelines

guideline documents	waste disposal
AIST	Nanomaterial waste, dust filter, collected waste liquid, cloth, etc. used for clean up shall be treated appropriately to prevent the secondary contamination and disposed of according to the waste separation method specified by the Institutes respectively.
CHS	collect in labeled enclosed hazardous waste containers with secure caps or covers including a description of the waste and the words "contains nanomaterials", loose contaminated material shall be double-bagged, labeled, sealed and disposed, dispose nanomaterials as hazardous waste
DOE-NRSC	characterize according to 40 CFR 261.10-38 as hazardous or nonhazardous waste, package in container compatible with contents, label "contains nanomaterials", include information characterizing known and suspected properties, collect contaminated material in plastic bag or sealable container, place into second bag or container
EPFL	treat contaminated liquid and solid wastes as to inactivate the nanoparticles, leave contaminated materials in the laboratory dustbin
Georgia Tech	place waste nanomaterials in puncture proof sealable containers or double bagged in 6 ml plastic bag which is labeled and disposed as hazardous waste
HSE-a	---
ISU	decontaminate equipment before disposal, treat nanomaterials as chemical waste
MIT	dispose as hazardous waste: pure nanomaterials, contaminated materials, liquids containing nanomaterials, and solid matrixes with nanomaterials at the surface; this does not apply for nanomaterials embedded in a solid matrix; collect contaminated materials in a labeled, closed double bag or double container
NASA-ARC	dispose nanomaterials and cleaning materials as hazardous waste
NSF	handle like potentially hazardous
ORC Worldwide	dispose as hazardous waste if the chemical or mixture is regulated as such by environmental regulations, otherwise dispose as special waste (incinerate, chemically treat, or immobilize/encase), for larger wastes special consulting, place contaminated material in bag or bucket for disposal
OUHSC-IBC	
Penn-EHRS	dispose as hazardous waste
TU Delft	treat quantities exceeding the milligram range as chemical waste, if the water solubility is low, nanomaterials with higher water solubility shall be treated according to toxicity class of the macroscopic material, nanoparticle residues in water from cleaning can be pured down the drain, according to hazardous chemical waste guidelines, contaminated materials must be disposed of as chemical waste
UBC	---
UC	according to hazardous chemical waste guidelines
UCI	treat like hazardous 'toxic' materials, nanoparticles in solution: dispose according to hazardous waste procedures for the solvent
UCSB	treat as hazardous 'toxic' materials, nanoparticles in solution: dispose according to hazardous waste procedures for the solvent
UD	dispose materials used in handling or cleaning nanomaterials in a separate closed waste container, concentrated nanomaterials: hazardous waste
VCU	dispose contaminated materials through incineration

2. Category G(eneral) nanomaterial guidelines

guideline documents	waste disposal
BAuA / VCI	
Hallock et al., 2009	as hazardous waste (not necessary for nanomaterials embedded in solid matrix), label waste
HMUELV	
Hoyt and Mason, 2008	hazardous waste, consult regulatory agency for ultimate disposal
HSE-b	hazardous waste, double-wrapped in sealed polypropylene bags, high temperature incineration at a hazardous waste incinerator (pyrolysis above 500 °C oxidises CNTs), documentation of disposal conditions and incineration temperature
IRSST	products containing nanoparticles shall be deposited in sealed bags for disposal
MHLW	shall be placed into an impervious, hard-to-tear bag and disposed in a proper way
NanoSafe Australia	treat as hazardous waste, double-bagged, in rigid impermeable container, disposed in a licensed land-fill site, bind within some matrix (e.g. concrete), disposal of some metal and metal oxide nanomaterials (i.e. QDs and ZnO) is restricted in australia because they are potent biocides
NIOSH	✓
OSHA-EUROPA	
PENNSTATE	call EHS office for hazardous waste determination, follow disposal requirements for bulk materials, carbon (flammable) and toxic metal containing material: hazardous waste
Safe Work Australia	
Surrey-ATI	in labelled container, hazardous waste,
Schulte et al., 2008	

3. Category L(aboratories) guidelines

guideline documents	waste disposal
AGS-BMAS	✓
DGUV	✓

ANNEX XIII. Documentation

Several recommendations regarding the correct documentation are provided by several nanomaterial guidelines for laboratory application.

1. Category S(pecific) nanomaterial guidelines

guideline documents	documentation generally	MSDS specific
AIST	The person responsible for the work handling nanomaterials shall establish a manual for the handling procedures, etc. and educate the workers well and have them comply with the handling procedures specified in the manual.	
CHS		
DOE-NSRC	Chemical Hygiene Plan, document the exposure to nanoparticle-exposed personnel, protocols for specific procedures, incorporation of specific procedural requirements into written procedures	✓
EPFL		
Georgia Tech		✓
HSE-a		
ISU	Laboratory Safety Manual, Standard Operating Procedures (SOP)	
MIT		✓
NASA-ARC	Laboratory Safety Plan (LSP), Standard Operating Procedures (SOP), Job Hazard Analysis Worksheet (JHA)	✓
NSF	incidents have to be recorded, documentation of training	
ORC Worldwide		
OUHSC-IBC	in vivo: IACUC, IBC; for humans: Institutional Review Board (IRB)	
Penn-EHRS		
TU Delft		
UBC		
UC		
UCI		✓
UCSB		✓
UD		
VCU	protocols which include measures for exposition mitigation; Chemical Hygiene Plan, SOPs, in vivo: IACUC Hazardous Chemical Information Page, Institutional Animal Care and Use Commitee, Institutional Biosafety Committee (IBC)	

2. Category G(eneral) nanomaterial guidelines

guideline documents	documentation generally	MSDS specific
BAuA / VCI		
Hallock et al., 2009		are inaccurate, often refer to micron scale materials
HMUELV	documentation of all tests and measures; generally: generation of a database for documentation for small- and medium enterprises (internet platforms available)	
Hoyt and Mason, 2008		×, no MSDS
HSE-b	✓	
IRSST	prevention program should be prepared, implemented, evaluated and constantly improved through an iterative documentation process	
MHLW	name of the worker, engaged period of work, general description of the nanomaterial-related work, shall be kept for a prolonged period	
NanoSafe Australia		
NIOSH		
OSHA-EUROPA		✓
PENNSTATE	in vivo: research protocol, document information on nanomaterial and protection measures, protocol has to be reviewed by EHS	may not have accurate information, potentially not transferable
Safe Work Australia		
Schulte et al., 2008		
Surrey-ATI	specific SOP, control of documents by supervisor	✓

3. Category L(aboratories) guidelines

guideline documents	documentation generally	MSDS specific
AGS-BMAS	✓	
DGUV	✓	