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Evaluation of information in nanomaterial safety data sheets and development of international standard for guidance on preparation of nanomaterial safety data sheets

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Abstract

Safety data sheets (SDSs) and labelling are the basic hazard communication tools for hazardous chemicals as regards their manufacture, storage, transport and other handling activities. Thus, in the context of the growing use of nanomaterials and nanomaterial-containing materials, this study evaluated the information provided in 97 nanomaterial-related SDSs according to the criteria set by the GHS (Globally Harmonized System of Classification and Labelling of Chemicals) and found that most of the SDSs did not include sufficient information on the safety of nanomaterials, such as their toxicity and physicochemical properties. The reasons for this lack of information in the nanomaterial SDSs can mainly be attributed to (1) a lack of toxicity and physicochemical property information on nanomaterials, (2) unawareness of the effectiveness of conventional exposure controls, such as local exhaust ventilation and encapsulation, and personal protective equipment (PPE), in protecting against nanomaterial exposure, (3) a lack of information on emergency and firefighting measures and (4) a lack of knowledge on how existing regulations apply to nanomaterials. Therefore, to create a consistent standard for the information provided on safety, health and environmental matters for manufactured nanomaterial-containing products, guidance for the preparation of nanomaterial-specific SDSs, including both nanomaterials and mixtures of nanomaterials with conventional non-nanoscale materials, was recently initiated by the ISO TC 229. Their guidance, in the form of a technical report, recommends that nanomaterial-related SDSs should be prepared based on a precautionary approach in terms of the toxicity and other risks associated with the nanomaterial contents within the mixture in question. One of the key recommendations in the technical report is to include additional physicochemical properties, including the particle size (average and range), size distribution aggregation/agglomeration state, shape and aspect ratio, crystallinity, specific surface area, dispersibility and dustiness, which help to distinguish the characteristics of nanomaterials from those of non-nanoscale materials. The technical report also recommends the preparation of SDSs for all nanomaterials and mixtures that meet the GHS criteria for physical, health or environmental hazards, and for all mixtures containing nanomaterials that meet the criteria for carcinogenic, toxic to reproduction or specific target organ toxicity in concentrations exceeding the cut-off limits for an SDS specified by the criteria for mixtures. Finally, the technical report recommends that SDSs be prepared for all nanomaterials, unless there is evidence that they are not hazardous.

Keywords: Nanomaterials, Safety Data Sheets (SDSs), international standards, guidance, GHS

Introduction

There is a current deficit in guidance on the safe handling of nanomaterials, although in many cases the degree of risk to workers and others exposed to nanomaterials is limited. Regulations such as the US OSHA hazard communication standard (1996), EU REACH regulation (2006) and Korean Industrial Safety & Health Act require the preparation of SDSs (safety data sheets) for all hazardous chemicals that are classified as hazardous according to the Globally Harmonized System of Classification and Labelling of Chemicals (GHS; or other classification criteria in countries that have not implemented the GHS), including those containing nanoscale materials, for use in relation to their manufacture, storage, transport or other handling activities. Yet there are still relatively few nanomaterial-specific SDSs, and those that exist generally provide insufficient information due to a lack of current information on the physical, health and environmental hazards (Safe Work Australia 2010; KATS 2009). There is some evidence that materials in a nanoform tend to be more hazardous, for example, more bioreactive or active, leading to higher toxicity, than the same material in a

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non-nanoscale form (Maynard & Kuempel 2005). Thus, the nanoparticle characteristics essential for determining the safety or toxicity of manufactured nanoscale materials need to be established and included when preparing an SDS. Recognising these problems, some countries have already published guidelines for preparing nanomaterial SDSs (SECO 2010) and evaluated SDSs and labels associated with the use of engineered nanomaterials (Safe Work Australia 2010). Several international organisations, such as the UNCETDG (United Nations Committee of Experts on the Transport of Dangerous Goods) and OECD WPMN (Organization for Economic Cooperation and Development, Working Party on Manufactured Nanomaterials), have also expressed concern about the lack of information on nanomaterials in current SDSs and requested international effort for the development of nanomaterial-specific SDSs. When the same issue was raised in December 2009 at the UNSCEGHS (United Nations Sub-Committee of Experts on the Globally Harmonized System of Classification and Labelling of Chemicals), it was decided that, given the current efforts by the European Union, OECD and ISO, the UNSCEGHS would postpone its consideration of the nanomaterial SDS issue until more information on the intrinsic properties and characteristics of nanomaterials became available (UNSCEGHS 2009). Meanwhile, the ISO TC 229 (International Organization for Standardization, Nanotechnology Technical Committee) accepted the new working item proposal led by Korea in 2009 and started developing guidance for the preparation of nanomaterial SDSs. The key issues in this guidance document are related to determining the differences between conventional chemical or non-nanoscale material SDSs (MSDSs) and nanomaterial SDSs, and identifying the main properties prescribing the uniqueness of nanomaterials as distinct from non-nanoscale materials. The resulting technical report on the preparation of nanomaterial SDSs is a supplement to ISO 11014 (2009) and the requirements laid down in the GHS document on hazard communication: SDSs (GHS 2009).

When preparing a nanomaterial SDS as a prime hazard communication tool for the workplace, the critical issue is to identify the uniqueness of nanomaterials as distinct from conventional chemicals and non-nanoscale materials as regards risk assessment, including dose–response, hazard identification, exposure assessment and risk characterisation, and extending into risk management and hazard communication. As defined by ISO TS 80004-1 (2010), a nanomaterial is a 'material with any external dimension on the nanoscale or having an internal structure or surface structure on the nanoscale', which clearly states that the nanoscale size is the most important differentiation from non-nanoscale materials. The physicochemical properties originating from this nanoscale size could then be a major consideration for risk assessment and hazard communication. The particle size and distribution in relation to the surface area have also been identified as critical parameters in assessing the environmental, health and safety aspects of nanomaterials. The size specificity with regard to the toxicity of a material has already been discussed in relation to its surface area (Powers et al. 2007; Oberdorster 2001). Chemical reactions take place on surfaces; therefore, a material with a high surface area can be expected to have a higher reactivity on a mass basis than the same material with a low surface area to volume ratio. As regards the aggregation/agglomeration state, aggregation has been defined as 'comprising strongly bonded or fused particles where the resulting external surface area may be significantly smaller than the sum of the calculated surface areas of the individual components', while agglomeration has been defined as a 'collection of weakly bound particles or aggregates or mixtures of the two where the resulting external surface area is similar to the sum of the surface areas of the individual components' (ISO TS 27687 2008). Agglomerate or aggregate particles are secondary particles that are larger, which might affect exposure. Therefore, if nanomaterials aggregate, the size of the aggregate is the particle size relevant to potential exposure rather than the size of the primary particle or nanomaterial (Oberdorster et al. 2005). Agglomerates that are weakly bonded are more likely to fragment than aggregates that are strongly bonded. Thus, particles originally manufactured as dispersed particles may behave differently in aquatic media and air media, thereby influencing the toxicological behaviour in testing media and the exposure characteristics in a workplace environment. The three basic shapes for nanomaterials are nanoparticles, nanofibres and nanoplates. The effects of the shape on the toxicity of nanomaterials have not been fully investigated, yet recent publications indicated that high aspect ratio nanofibres (HARN) have been shown to have the potential to cause an asbestos-like response in animal studies (Poland et al. 2008). The surface chemistry is considered to be the portion of the nanomaterial in direct contact with the dispersing medium or biological structures. Thus, surface coating nanomaterials to reduce agglomeration influences the surface chemistry of the particles, and changing the surface function may play a significant role in determining the risk of a particular nanomaterial (Limbach et al. 2007). The composition and crystalline structure are already well established as significant toxicologic determinants at the molecular level and are also becoming increasingly recognised as significant for many nanomaterials. For example, crystalline silica or asbestos exhibits pronounced toxicity when compared with its amorphous counterpart. The zeta potential is a function of the surface charge of a particle or any adsorbed layer at the interface and the nature and composition of the surrounding medium in which the particle is suspended (Borm et al. 2006). The surface charge plays a key role in determining the degree of colloidal interaction, which is itself a function of the pH and ionic strength of the bulk solution, and the bioavailability of a compound when considering mass transport through charged membranes as related to exposure (ISO TR 13014 2012). Nanomaterials can interact with the liquid-phase components partially or totally, yielding soluble or dispersed forms that may influence the overall toxicity and fate processes. Therefore, these unique properties of nanomaterials need to be considered for risk assessment and hazard communication, especially in the preparation of nanomaterial SDS.

Accordingly, this report evaluates the information provided in existing nanomaterial SDSs, including their preparation in accordance with GHS guidance and inclusion of the nano-specific information presented above, discusses the physicochemical properties suitable for nanomaterial SDSs and outlines the current efforts to develop an international standard for nanomaterial SDSs.

Materials and methods

Collection of SDSs

Ninety-seven SDSs for nanomaterials and products containing nanomaterials were collected based on an internet search using keywords such as 'nano' for materials related to 14 representative nanomaterials that are undergoing OECD WPMN safety testing. Every attempt was made to obtain SDSs related to the 14 representative nanomaterials. Most of the evaluated nanomaterial SDSs were produced internationally, and no Korean-produced SDS was evaluated. No formal analysis of the representativeness of the collected nanomaterial SDSs was conducted. All the nanomaterial SDSs were prepared in English. The numbers of SDSs evaluating each nanomaterial are presented in Table I.

Analysis of nanomaterial SDSs

The quality of the SDSs was checked based on the reliability and accuracy of the contents according to the criteria prescribed in the GHS. The reliability of each MSDS was assessed in terms of the overall relevance and accuracy of the information presented, while the accuracy was assessed in terms of the information presented and either prior knowledge of a property or inconsistencies for a property between different sections of the MSDS (Safe Work Australia 2010). The SDSs were also evaluated as to whether they contained relevant, accurate and contextual information on the hazards, risks and control measures specific to nanomaterials. In particular, the inclusion of nanomaterial-specific information according to the physicochemical properties covered in section 9 of the GHS (2009) or ISO 11014 (2009) was checked. The evaluation of the nanomaterial SDSs according to each section is shown in Table II. Furthermore, whether the information provided in the nanomaterial SDSs was sufficient for protecting worker safety and health was also evaluated in the light of newly emerging knowledge on nanomaterial properties. The evaluation of section 9 (*Physicochemical Properties*) covered the inclusion of important information on the intrinsic properties of the nanomaterial, as listed in Table III based on the GHS criteria. Finally, since the toxicity of manufactured nanomaterial exposure covers a broad range and can be attributed to differences in composition, as well as differences in size, shape, surface area, surface chemistry, crystallinity and degree of agglomeration/aggregation, the SDSs were evaluated for the inclusion of these properties, which are regarded as essential for the toxicity assessment of nanomaterials (ISO TR 13014 2011), and assessed on the sufficiency of information relevant to workplace health and safety management.

Table I. Evaluated safety data sheets for nanomaterials and products containing nanomaterials.

Nanomaterial	Number of SDSs
Fullerene	6
SWCNT	6
MWCNT	9
Silver nanoparticle	8
Fe nanoparticle	6
Carbon black	10
Titanium dioxide	16
Aluminium oxide	10
Cerium oxide	8
Zinc oxide	7
Silicon dioxide	8
Polystyrene	7
Dendrimer	4
Nanoclay	5

MWCNT, multi-walled carbon nanotube; SDSs, safety data sheets; SWCNT, single-walled carbon nanotube.

Results

Ninety-seven SDSs were selected from an internet search. The selection of the 97 SDSs was based on 14 representative nanomaterials in the OECD WPMN safety testing program. Although recently added to the safety testing program, gold nanoparticles were not included in the current selection. With the exception of dendrimer, more than five SDSs were selected per nanomaterial and analysed (Table I). Table IV describes the deficiencies of the nanomaterial SDSs: sections 1–8. Seventy-three percent of the nanomaterial SDSs included a hazard classification, while 27% did not contain any hazard classification. The most frequent classification of the manufactured nanomaterials was as an irritant for the skin or eyes (73%, 71/97 SDSs). Most products (85%, 82/97 SDSs) did not provide any nanomaterial-specific data, and the data used for hazard classification of the nanomaterials were mostly derived from non-nanoscale material data. Vague and potentially misleading descriptions, such as 'may be dangerous', 'no health effects' and 'safe under most conditions of use' were used in many nanomaterial SDSs. Only one SDS included a precautionary statement for labelling. Graphite or carbon black CAS numbers were used for some carbon-based nanomaterials, such as single-walled carbon nanotubes (SWCNTs; 50% 3/6 SDSs) and multi-walled carbon nanotubes (MWCNTs; 56%, 5/9 SDSs). Sixty percent of the SDSs did not include any composition information, while 40% included composition information on the nanomaterial ingredients. The SDSs for nanomaterials in a suspension containing capping and coating agents or stabilisers neither specified the concentrations or concentration ranges of the mixtures nor provided relevant information, such as the occupational exposure limits (OELs) and toxicity information, required by the GHS. Sixty-two percent of the SDSs did not include information on firefighting measures, 22% made no mention of the use of personal protective equipment (PPE) for firefighters and 76% of the SDSs had no information on accident release measures for nanomaterials. Nanopowders can combust much more rapidly than equivalent materials with larger particle

Table II. Analysis of nanomaterial safety data sheets (SDSs).

SDS section	Evaluated items
1. Identification of substance or mixture and supplier.	(1) Proper description of product identifier, (2) recommended uses and restrictions, (3) name, full address and phone number of supplier and (4) emergency phone number
2. Hazard identification	(1) Hazard classification of nanomaterial or mixture, (2) appropriate precautionary statement according to ingredients and (3) information on other hazards not included in classification
3. Composition/information on ingredients of nanomaterials	(1) Chemical identity of nanomaterial, (2) appropriate common names and synonyms of nanomaterial, (3) CAS number or other identifier of nanomaterial and (4) ingredient concentrations
4. First-aid measures	(1) proper description of first-aid measures in case of eye contact, skin contact, inhalation and ingestion, (2) acute/delayed symptoms and effects, (3) medical attention and (4) special treatment
5. Firefighting measures	(1) inclusion of description of suitable extinguishers, (2) specific hazards arising from material decomposition and (2) special protective actions for firefighters in case of fire arising from nanomaterial or mixture
6. Accident release measures	(1) Inclusion of proper description of personal precautions and protective equipment, (2) emergency procedures, (3) environmental precautions and (4) cleaning and containment methods
7. Handling and storage	inclusion of proper description of safe handling and storage of nanomaterial
8. Exposure control/personal protection	(1) Inclusion of recommendations on control parameters, such as use of local exhaust ventilation or enclosed system, (2) listing of occupational exposure limits (OELs) including notations for nanomaterial and each ingredient in mixture, despite scarcity of nanomaterial-specific OELs, (3) inclusion of individual protection measures, such as personal protective equipment (PPE) and (4) recommended use of PPE certified by CEN, NIOSH or local authorities
9. Physical properties	(1) Inclusion of important information on intrinsic properties of nanomaterial, as based on GHS criteria and (2) inclusion of nanomaterial-specific information, such as particle size, shape, surface area, surface chemistry, aggregation/agglomeration and crystallinity
10. Stability and reactivity	(1) Inclusion of description of stability, hazardous reactivity and conditions to avoid, such as static or vibration, (2) chemicals to avoid contact with and (3) hazardous decomposition products of nanomaterial
11. Toxicological information	(1) Inclusion of description of possible routes of exposure, (2) acute and chronic health effects and (3) occupational exposure levels, if any
12. Ecotoxicity	(1) Inclusion of description of ecotoxicity, (2) biodegradability, (3) bioaccumulation and (4) fate in soil
13. Disposal considerations	Inclusion of appropriate disposal methods and disposal considerations
14. Transport information	(1) Inclusion of UN number, (2) UN proper shipping name, (3) transport hazard class, (4) package group, (5) environmental hazards and (6) special precautions
15. Regulatory information	Inclusion of respective national regulations regarding nanomaterials
16. Other information	Inclusion of information on preparation and revision of nanomaterial SDSs

sizes (Health and Safety Laboratory 2010). For example, the minimum ignition energies of some powders containing nanomaterials have been found to be lower than the equivalent material on a micrometre scale (Health and Safety Laboratory 2010). In the case of aluminium oxide, which is well known as a combustible solid, a fine aluminium dust can easily be ignited and cause an explosion, yet there was no mention of the risk of dust explosions in the relevant SDSs. Despite the lack of OELs for nanomaterials at the time the SDSs were written (OELs for ultrafine TiO_2 and carbon nanofibres and CNTs have recently been suggested by the US NIOSH 2010, 2011), 56% of the SDSs did not include or suggest OELs for the non-nanoscale materials if there were no OELs for the nanomaterials. Although 44% of the SDSs included OELs for the nanomaterials, it was not noted that these OELs were for non-nanoscale materials. While some SDSs for CNTs and fullerenes did suggest exposure limits, the suggested OELs were only for graphite or carbon black (1/6 SDSs for fullerene, 2/6 SDSs for SWCNTs and 4/9 SDS for MWCNTs). Thirty-six percent of the SDSs did not mention the use of engineering controls to mitigate nanomaterial exposure and 65% did not recommend the use of PPE to avoid nanomaterial exposure, indicating a lack of information on nanomaterial exposure mitigation measures. The majority of the nanomaterial SDSs did not include information on the physicochemical properties, and just mentioned 'no data' or 'not applicable' due to the lack of physicochemical information on nanomaterials, as well as the non-nanoscale materials, in part due to the difficulties involved in obtaining physicochemical data on insoluble particles. A few SDSs provided information on the size of the nanomaterials (Table III), including the length and surface area based on electron micrographs. Many of the SDSs lacked information on the stability (90%), hazardous reactivity (63%), conditions to avoid, such as static or vibration (49%), and chemicals to avoid contact with (51%) (Table V). Although 64% of the SDSs provided possible routes of exposure, such as inhalation, 36% of the SDSs failed to mention possible routes of exposure in the toxicological information section. Many of the SDSs also failed to provide acute and chronic health effects (48%), a toxicity estimation (51%) and OELs (65%). In many cases, there was no toxicological information or the information provided was non-nanoscale material data. Some SDSs for carbon black or

Table III. Deficiencies of nanomaterial safety data sheets (SDSs): section 9, physicochemical properties. () indicates percent.

Item	Described	Not described
Appearance	94 (97)	3 (3)
Odour	48 (49)	49 (51)
Odour threshold	1 (1)	96 (99)
pH	13 (13)	84 (87)
Melting point/freezing point	49 (51)	48 (49)
Initial boiling point and range	26 (27)	61 (73)
Flash point	14 (14)	83 (86)
Evaporation rate	0	97 (100)
Flammability	0	97 (100)
Upper/lower flammability or explosive limits	6 (6)	
Vapour pressure	12 (12)	85 (88)
Vapour density	41 (42)	56 (58)
Relative density	33 (34)	64 (66)
Solubility	46 (47)	51 (53)
Partition coefficient, n-octanol/water	0 (0)	97 (100)
Auto-ignition temperature	11 (11)	86 (89)
Decomposition temperature	1 (1)	96 (99)
Viscosity	1 (1)	96 (99)
Molecular weight	32 (33)	65 (67)
Particle size, surface area, crystallinity	19 (20)	78 (80)

TiO_2, which have already been classified as IARC 2B carcinogens, did not mention the carcinogenicity of these particles. Most of the SDSs did not provide any information on the ecotoxicity, such as the aquatic toxicity (86%), biodegradability (99%), bioaccumulation (97%) and fate in soil (100%) (Table V), indicating a scarcity of ecotoxicity data or difficulties in performing ecotoxicity testing for nanomaterials. Furthermore, the nanomaterial SDSs lacked information on transportation, such as the UN number (86%), UN shipping name (90%), class of transportation (88%) and container class (86%), or relevant regulatory information related to occupational safety and health (86%), hazardous substance control (100%), dangerous goods (100%) and disposal (100%) (Table V), since relatively few formal regulations for nanomaterials are in effect. Overall, most of the nanomaterial SDSs lacked basic nano-specific information for the protection of workers and safe management in the workplace, such as physicochemical properties differentiating nanomaterials from non-nanoscale materials, toxicological and ecotoxicological information, firefighting and accident release measures, handling and storage, exposure control/personal protection and disposal information.

Discussion

As shown by the results, many of the nanomaterial SDSs lacked significant information on health and environmental effects, exposure control, emergency and firefighting measures, and regulatory information. The reasons for this lack of information in the nanomaterial SDSs were mainly related to (1) a lack of toxicity and physicochemical property information on nanomaterials, (2) unawareness of the effectiveness of conventional exposure controls, such as local exhaust ventilation and encapsulation, and the effectiveness of PPE in protecting against nanomaterial exposure, (3) a lack of information on emergency and firefighting measures and (4) ignorance on the application of existing regulations to nanomaterials. For example, even though nanosilver and nano TiO_2 are nanomaterials, they are still regulated as hazardous chemical substances under existing regulations (e.g. Industrial Safety and Health Acts in Korea). Notwithstanding, many nanomaterial SDSs did not mention the respective regulations in relation to hazardous chemicals.

As the commercial availability of nanomaterials continues to expand, better SDSs with more comprehensive information are required for the market. While the creation of new regulations for nanomaterials remains under consideration, existing regulations are being revised meantime. For example, the US EPA TSCA (Toxic Substance Control Act 1976) and EU REACH (Restriction evaluation assessment of chemicals 2006) regulations have been extended to the control of nanomaterials. Although the SDS preparation prescribed by the hazard communication standard OSHA (Occupational Safety & Health Act) does not explicitly mention the requirement of SDSs for nanomaterials, REACH and other regulations do require SDSs for nanomaterials.

Recognising the insufficiency of the information included in nanomaterial SDSs and the need for an instrument to promote the provision of comprehensive information in nanomaterial SDSs, the current authors proposed the initiation of a technical report on the preparation of nanomaterial SDSs. This project was approved by the member countries of May 16 2009 ISO TC 229 on (ISO TC 229 2012). The scope of this technical report is to create a consistent standard when providing information on safety, health and environmental matters for manufactured nanomaterial-containing products. It also provides supplemental guidance for the preparation of nanomaterial-specific SDSs, including both nanomaterials and mixtures of nanomaterials with conventional non-nanoscale materials. For mixtures containing nanomaterials, the use of this technical report and the inclusion of nano-relevant details in the SDS should be determined based on a precautionary approach in terms of the toxicity and other risks associated with the nanomaterial contents within the mixture in question. The technical report recommends providing SDSs for all nanomaterials, regardless of whether or not the non-nanoscale material is classified as hazardous, unless existing data indicate that the nanomaterial is non-hazardous. Although there is no legal requirement to provide an SDS for a material that is not classified as a hazardous chemical, it is still good practice to do so, since an SDS is a well-accepted and effective method for the provision of workplace health and safety information. In addition, there is currently a lack of formal classifications of manufactured nanomaterials and increasing evidence regarding the toxicity of some nanoscale materials. The technical report recommends that an SDS should contain a brief summary/conclusion of the data it provides, making it easy for any reader to identify all the hazards, including any associated with the material's nanostructure. In addition to the minimum information required by the GHS, the SDS should also contain all other relevant information about the

Table IV. Deficiencies of nanomaterial safety data sheets (SDSs): sections 1–8. () indicates percent.

SDS section	Section items	Described	Not described
1. Identification of substance or mixture and supplier	Product identifier	97 (100)	0
	Recommended uses and restrictions	0 (0)	97 (100)
	Supplier details	95 (98)	2 (2)
	Emergency phone	77 (79)	20 (21)
2. Hazard identification	Hazard classification	71 (73)	26 (27)
	Precautionary statement with label elements	1 (1)	96 (99)
	Other hazards	21 (22)	56 (58)
3. Composition/information on ingredients of nanomaterials	Chemical name	96 (99)	1 (1)
	Common name and synonyms	63 (65)	34 (35)
	CAS number or identifier	91 (94)	6 (6)
	Ingredient concentrations	58 (60)	39 (40)
4. First-aid measures	Eye contact	95 (98)	2 (2)
	Skin contact	95 (98	2 (2)
	Inhalation	94 (97)	3 (3)
	Ingestion	95 (98	2 (2)
	Acute/delayed symptoms and effects	10 (10)	87 (90)
	Medical attention and special treatments	12 (12)	85 (88)
5. Firefighting measures	Suitable extinguishers	88 (91)	9 (9)
	Specific hazards arising from material decomposition	37 (37)	59 (61)
	Special protective actions for firefighters	76 (78)	21 (22)
6. Accident release measures	PPE	74 (76)	23 (24)
	Environmental protection measures	31 (32)	66 (68)
	Cleaning and containment methods	95 (98)	2 (2)
7. Handling and Storage	Safe handling	95 (98)	2 (2)
	Safe storage	93 (96)	4 (4)
8. Exposure control/ personal protection	OEL	54 (56)	43 (44)
	Engineering controls	62 (64)	36 (36)
	PPE	94 (97)	3 (3)
	PPE recommended by CEN or NIOSH	63 (65)	34 (35)

OEL, Occupational exposure limit; PPE, personal protective equipment.

material, including its use. SDSs should be prepared for all nanomaterials, nanostructured materials and nanomaterial-containing substances, except when (1) testing or assessment results that meet the requirements of competent authorities have indicated that the materials are non-hazardous or (2) when it is not envisaged that the manufactured nanomaterials can be released as discrete particles (e.g., if they have been used to form a surface coating and are strongly bound in the matrix) and the non-nanoscale composite material does not exhibit toxicity on its surface. One of the key recommendations of the technical report is to include additional physicochemical properties that help to define the characteristics of nanomaterials as distinct from non-nanoscale materials. The physicochemical properties of nanomaterials referred to in the technical report are additional properties that are not described in the GHS physicochemical property section, yet regarded as essential information on nanomaterials and distinct from the information provided on non-nanoscale materials in order to manage the workplace environment and protect workers. These additional physicochemical properties of nanomaterials, as recommended by the experts involved in the technical report project, include the particle size (average and range), size distribution, aggregation/agglomeration state, shape and aspect ratio, crystallinity, specific surface area, dispersibility and dustiness (Table VI). The solubility and composition were excluded from the list as they are already required under the GHS criteria. The surface chemistry and surface charge were also excluded, since SDSs are meant to provide workplace-relevant information. Instead, dustiness in relation to health hazards and environmental pollution, and also as a cause of fires and explosions was added to the list. Some experimental studies in animals have shown that the biological response to nanoparticles tends to be greater than that for the same mass of larger particles of the same chemical composition. Thus, if toxicological hazards exist for the non-nanoscale material, this information should also be identified and included. The technical report also recommends the inclusion of additional toxicological and ecotoxicological information, such as the biopersistence and biodurability, neither of which is included in the GHS (Table VI). The technical report indicates that conventional exposure mitigation strategies, such as engineering controls and PPE, are still effective for controlling nanomaterial exposure and personal protection (Han et al. 2008). The technical report also advocates the listing of existing workplace limit values for all the ingredients listed under Section 3.4 'Composition/information on ingredients', if available, along with the exposure limits to be observed. Finally, the technical report recommends the preparation of SDSs for all nanomaterials, except where data indicate they are non-hazardous. The technical reports further recommends the preparation of SDSs for all nanomaterials and mixtures that meet the GHS criteria for physical, health or environmental

Table V. Deficiencies of nanomaterial safety data sheets (SDSs): sections 10–16. () indicates percent.

SDS section	Section items	Described	Not described
10. Stability and reactivity	Stability	88 (91)	9 (9)
	Hazardous reactivity	36 (37)	61 (63)
	Conditions to avoid, such as static discharge or vibration	48 (49)	49 (51)
	Chemicals to avoid contact with	49 (51)	48 (49)
	Hazardous decomposition products	60 (62)	37 (38)
11. Toxicological information	Possible routes of exposure	62 (64)	35 (36)
	Acute and chronic health effects	50 (52)	47 (48)
	Toxicity estimation	48 (49)	49 (51)
	OELs	34 (35)	73 (65)
12. Ecotoxicity	Ecotoxicity	14 (14)	83 (86)
	Biodegradability	1 (1)	96 (99)
	Bioaccumulation	3 (3)	94 (97)
	Soil	0 (0)	97 (100)
13. Disposal considerations	Disposal methods	8 (8)	89 (92)
	Disposal considerations	8 (8)	89 (92)
14. Transport information	UN number	14 (14)	83 (86)
	UN proper shipping name	10 (10)	87 (90)
	Transport hazard class	12 (12)	85 (88)
	Packaging group	14 (14)	83 (86)
	Environmental hazards	0 (0)	97 (100)
	Special precautions	0 (0)	97 (100)
15. Regulatory information	Occupational Safety & Health Acts	15 (15)	82 (85)
	Hazardous Substance Control Acts	0 (0)	97 (100)
	Dangerous Goods Acts	0 (0)	97 (100)
	Disposal Acts	0 (0)	97 (100)
	Other relevant regulations	74 (76)	23 (24)
16. Other information, including information on preparation and revision of SDS	Sources of information	69 (71)	28 (29)
	Initial preparation date	45 (46)	52 (54)
	Revision number and date	71 (73)	26 (27)
	Others	92 (95)	5 (5)

OELs, Occupational exposure limits; SDS, safety data sheet.

hazards, and for all mixtures that contain nanomaterials that meet the criteria for carcinogenic, toxic to reproduction or specific target organ toxicity in concentrations exceeding the cut-off limits for an SDS specified by the criteria for mixtures. Despite the use of cut-off values based on weight for the hazard classification of mixtures containing nanomaterials, the authors of nanomaterial SDSs should also consider the importance of the number and surface concentration of nanomaterials.

As the technical report is still under development, comments are welcome to improve the quality of the document. The technical report will include a list of analytical methods for defining the additional physicochemical properties of nanomaterials. Surely, such international collaborative efforts will help to build the reliability of nanomaterial SDSs and provide more useful information for protecting worker health and safety.

Table VI. Additional information on nanomaterial safety data sheets (SDSs).

SDS section	Additional information
Physicochemical properties	Particle size (average and range), size distribution aggregation/ agglomeration state, shape and aspect ratio, crystallinity, specific surface area, dispersibility and dustiness
Toxicology	Biopersistence, biodurability
Ecotoxicology	Biopersistence, biodurability

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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