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European Association of Metals

Guidance on the Assessment of Occupational Exposure to Metals Based on Monitoring Data

Final Report

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1 Introduction and objectives of this guidance

This guidance for the assessment of occupational exposure based on monitoring data aims at providing information to facilitate harmonised generation and analysis of exposure data in the metals' industry.

Harmonisation is important to ascertain easily accessible and comparable exposure databases amongst metal associations, maximising their value for re-use for several purposes. These purposes include: (i) exposure assessments as required under the REACH Regulation (Regulation (EC) No 1907/2006) including those required for the application for authorisation of uses, (ii) OEL setting at the European or national level, (iii) compliance checking, (iv) checking/improving the efficiency of localised exposure controls and (v) use in the calibration of exposure modelling tools.

In addition, harmonisation is important when historical (already existing and still relevant) data are to be merged with recently generated exposure data. Only appropriately recorded contextual information[1] can ensure a consistent exposure database containing historical and recent exposure data.

Consequently, this guidance addresses aspects of monitoring methodology and data reporting relevant for occupational exposure assessments within the entire supply chain of metals (and their compounds) rather than providing detailed guidance to address specific questions of individual metal commodities/sites.

While it is acknowledged that exposure in the workplace may occur via inhalation, dermal contact and via (inadvertent) ingestion, this document focusses on monitoring of inhalation exposure as the main route of exposure[2]. For the remaining types of monitoring data, some relevant issues are discussed in Section 2.2 and reference is given to other guidance documents. It should also be noted that in addition to external exposure, internal exposure may be measured through bio-monitoring if required pre-requisites are fulfilled.

An exposure assessment based on monitoring data entails the mathematical analysis of the recorded data. More specifically, it entails the derivation of an exposure level from a distribution of individual exposure values. Since the purpose of the exposure assessment pre-defines the sampling methodology to a considerable extent, this guidance addresses the specific requirements for a sound data analysis. Particular focus is thereby given to exposure assessments as required under REACH (and indicated in ECHA guidance[3]).

In this guidance, considerations of particle size investigations are limited to the fractions of dusts as mentioned in BS EN 481 whereas these considerations do not cover direct measurements of (more complete) particle size distributions in the workplace.

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[1] Contextual information = auxiliary information required to qualify a dataset as reliable (see also Section 3.1)

[2] Dermal and inadvertent ingestion exposure may also play an important role in workers' exposure. However, the need to assess these routes considerably varies between metals and sampling methodology is currently less developed and standardised.

[3] It is noted that the relevant REACH guidance on occupational exposure (R.14) has been updated in August 2016. Whereas the principles mentioned remain the same in the recent version, some details have been modified. In particular, Table R.14-2 has been removed. A reference to this table (and the considerations behind it) has been nevertheless retained in this document providing indicative information on the required number of measurements for a representative exposure assessment. Further work is ongoing on this aspect.

The provided guidance applies to measurements of most aerosols in the workplace, however, in some instances, alternative methods that are potentially more suitable exist (e.g. for welding fumes). They are however not part of this guidance. Finally it should be noted that exposure monitoring of nano particles is not in the scope of this guidance.

The information included in this document does on purpose address generic issues related to monitoring of occupational exposure to metals. However, references to information sources for aspects outside the scope of this guidance and for metal-specific guidance, where available, have been included in Section 4.

2 Monitoring methodology

As explained below, the actual purpose of the occupational exposure assessment predefines the monitoring methodology to a considerable extent. Only, a well thought-through sampling strategy, carried out with the appropriate sampling equipment, will facilitate a sound data analysis and exposure assessment.

For the selection of the monitoring methodology one needs to consider:

(i) the scope of the monitoring campaign (2.1),
(ii) the sampling strategy (and actual sampling procedure) (2.2),
(iii) the sampling equipment (2.3), and
(iv) the quantification of exposure levels from the generated samples (2.4).

These 4 aspects should be defined in the context of the objectives of the exposure assessment. Often, at the level of metal associations, such objectives are related to setting up or amending a representative exposure database. The purpose of such a database may vary: to serve as data source for, e.g. occupational risk assessments for registration and/or authorisation under REACH, precautionary exposure assessments as part of product stewardship or hazard identification, demonstration of appropriateness of specific risk management measures or other purposes including the use for the calibration of exposure models. However, the requirements for the generation of exposure data to meet these objectives can be described on a generic level, related to the aforementioned 4 aspects and are described below. While information in Sections 2.1 and 2.2 also refers to dermal monitoring and bio-monitoring, subsequent sections (equipment and exposure quantification) are exclusively focussing on inhalation monitoring data.

2.1 Defining the scope of a monitoring campaign

Before developing a sampling strategy (ii), the actual scope of the potential monitoring campaign needs to be defined. A challenge when defining the scope is the balance to be found between two competing concepts, namely the specificity and the representative nature of data (sets). The definition of the scope will allow identifying the data needs.

> *For example, if an assessment is to cover an entire sector, data would be required from several sites to ensure representativeness of the data set. The specificity of such an exposure assessment would be less because of likely site-specific differences.*

2.1.1 Specificity of monitoring data

In order to assess exposure in a meaningful context, any exposure data used need to be specific to the exposure situation[4] to be assessed. An exposure situation is defined by the operational conditions (OC) prevailing and risk management measures (RMM) effective during the exposure period to be assessed. It is up to the exposure assessor to define the boundaries for individual exposure situations since variations in the conditions of use[5] (OC and RMM) are common when, for example, multiple sites are concerned. Plausibility considerations on the substance- and process-intrinsic emission potential (and other OC) and their modification by the prevailing RMM could be used.

> *For example, occupational exposure during raw material handling (emptying of received containers into storage silo) shall be assessed. The substance may be handled either as metal chips or in powder form, whereas other operational conditions are similar and implemented risk management measures vary in a way that powder handling is completely enclosed and the handling of the metal chips may be conducted with or without local exhaust ventilation (LEV) present. In this example, 3 exposure situations may be defined: (i) enclosed handling of metal powder, (ii) handling of metal chips (LEV present) and (iii) handling of metal chips (LEV not present). These correspond to three sets of exposure data.*

Further information on how to define exposure situations could be found in, for example, EN 689. The following discriminators are to be considered: job functions, tasks, work patterns and techniques, production processes, workplace configuration, safety precautions and procedures, ventilation installations and other forms of engineering control, emission sources, exposure times, workload, etc. when defining the boundaries of an exposure situation. A similar and often used term for exposure situation in this context may be “Similar Exposure Group” (SEG). Reference is given to the current draft version (June 2016) of EN 689 (prEN 689) providing further information on SEGs.

2.1.2 Representative nature of monitoring data

As already mentioned above, differences in the implementation of OC and RMM at the level of individual sites and inter- and intra-worker differences could lead to considerable variation in exposure levels even within the same exposure situation. In order to address such variation, repeated measurements of the exposure situation are required at different sites and for different workers. The required number of measurements per exposure situation varies with the level of variation and the required safety margin. An indication of the required minimum number of observations can be found in the previous REACH guidance R.14[6], Table R.14-2 (see also Section 3.2.5.1.1).

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[4] Under REACH, an exposure situation may be translated into a contributing exposure scenario. A contributing exposure scenario is defined by a single set of operational conditions and risk management measures. Consequently, observed variation in exposure levels may be mostly attributable to personal behaviour.

[5] Under REACH, operational conditions and risk managements measures are commonly referred to as „conditions of use“.

[6] ECHA guidance R.14 has been updated in August 2016. Although Table R.14-2 has been removed from the guidance, reference to this table is still maintained in this guidance.

<u>For example</u>, the 3 example exposure situations introduced above may be extended by a situation in which powder and metal chips are handled together, so that a differentiation according to the physical form would not reflect actual work practice. For such a combined situation, however, higher variation of exposure levels can be expected, so that more data points are required to still conduct a robust exposure assessment.

2.1.3 Identifying data needs

For most metals and metal compounds, (inhalation) monitoring data already exist. If such data are (still) reflective of current work practice and if the qualifying contextual information (see Section 3.1) is available, they should be (re-)used as much as possible. An inventory of exposure situations to be assessed together with the number of available measurements is therefore a prerequisite for the planning of any monitoring campaign. Such inventory should also include the variation and exposure estimate based on the historical data if such calculations are already possible. When compared with the minimum number of required measurements (please see Section 3.2.5.1.1), data gaps can be identified and taken into account for defining the scope of the monitoring campaign. In addition, sector-coverage in terms of monitored sites and workforce should be taken into account.

<u>For example</u>, where a given exposure situation to be monitored is relevant for several sites, the number of measurements should be balanced between these sites as much as possible taking into account the number of exposed workers at the individual sites if the purpose is a sector-wide exposure assessment.

2.2 Sampling strategy

To enable robust (sector-wide) exposure assessments, monitoring should be conducted on a representative basis, i.e. representative of regular working practices and workplace conditions. Representative sampling therefore excludes any sampling during non-standard settings (e.g. incidents) within the exposure situation to be assessed. The term “worst-case sampling” is therefore misleading and should instead refer to sampling in a worst-case exposure situation (which should not be grouped with a standard situation). Whether or not such “worst case” situations are relevant for the purpose of the specific risk assessment[7] can only be assessed on a case-by-case basis whereas the same basic principles for monitoring would still apply for the worst-case situation.

If data are obtained under the principles outlined in this document, it is assumed that they could be re-used, e.g. for checking of compliance with an OEL at the company level where such data have been obtained. Whether or not these data indeed fulfil specific requirements as set in national legislation can only be decided by the responsible occupational hygienist on-site by considering the specific metal substance concerned.

Thus, Section 4 provides an overview of available substance-specific guidance from European sector organisations and a (non-exhaustive) selection of existing European and American sampling standards.

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[7] For example, incidents and irregular, unscheduled repair work may be considered being outside the scope of standard REACH exposure scenarios and related risk assessment, whereas the protection of workers’ health in such situations would be ensured by separate measures.

Types of monitoring for different exposure routes are briefly described in the following sections.

2.2.1 Dermal exposure monitoring

Dermal exposure monitoring is conducted less frequently compared to inhalation exposure monitoring. As explained in detail in the HERAG guidance[8] (HERAG, 2007), different sampling techniques exist for the measurement of potential or actual dermal exposure. It is already stated in the aforementioned guidance that measurements of dermal exposure are more difficult to interpret when compared to inhalation exposure data. Two conclusions of the aforementioned guidance are of particular relevance for an appropriate sampling method in the metals' industry:

> *"[…] neither the use of cotton gloves nor the bag-wash method with their inherent limitations are preferable methods […]".*
>
> *"[…] Particularly in the case of dermal exposure monitoring of inorganic compounds, it is proposed for future measurements to make use of the wipe-sampling methodology. The degree of standardisation and validation obtained with this method to date should facilitate the collection of a comparable dataset for the future."*

2.2.2 Oral exposure monitoring

For workers, oral exposure is often assumed to be sufficiently controlled by strict occupational hygiene practices (e.g. no eating and smoking in the workplace, washing hands before eating, etc.) in most situations. However, inhalation of particles and subsequent swallowing may still lead to inadvertent oral exposure.

Monitoring of oral exposure is however not further addressed in this guidance. In many cases bio-monitoring (see Section 2.2.3) may be an alternative way to assess exposure resulting from all routes, including the oral route.

2.2.3 Bio-monitoring

Bio-monitoring represents an additional tool to assess human exposure to a subset of chemicals. In bio-monitoring, either body fluids such as blood or urine, or tissues are examined in order to analyse levels of specific chemicals (either the agent of interest or its metabolite). In addition, measurements of any indicator of effect (e.g., pulmonary function testing) can be considered as bio-monitoring. While for some chemicals, the use of bio-monitoring is less suitable[9], the determination, for example, of blood lead levels is a common procedure in Europe. Bio-monitoring data reflect uptake through all routes of exposure and exposure in and outside the workplace. The uncertainty of the assessment of internal exposure (that is after uptake) is less compared to substances for which exclusively external

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[8] http://www.ebrc.de/downloads/HERAG_FS_01_August_07.pdf

[9] Substances for which (i) toxicokinetics (uptake into, distribution in and/or excretion from the human body) are not sufficiently investigated, (ii) an internal toxicological reference value is not available and/or (iii) the required sample of body fluid or tissue is difficult to obtain hindering an effective exposure/health monitoring of workers. In addition, if local effects in the lung are of concern, any measure of internal exposure may not adequately quantify the actual lung burden relevant for such type of effect so that external exposure monitoring may be more suitable or should be used in addition to bio-monitoring in this situation.

exposure levels (dermal and/or inhalation exposure levels) are available. Also exposure via the oral route (e.g. after inadvertent ingestion or hand-to-mouth transfer) is reflected in bio-monitoring data. Several prerequisites are however to be fulfilled for an effective use of bio-monitoring data. The most important is potentially the availability of an internal toxicological threshold value or, if such a value is not available, the possibility to recalculate from internal exposure levels obtained in bio-monitoring to an external threshold value. Because of its highly substance-specific requirements, bio-monitoring is not further addressed in this guidance.

2.2.4 Inhalation exposure monitoring

2.2.4.1 Type of inhalation monitoring

In principle, 2 types of inhalation monitoring approaches may be distinguished at first instance: personal or static monitoring. For risk assessment purposes, a clear preference should be given to personal sampling as naturally being more relevant for personal exposure. For assessments under REACH, it is stated in the R.14 guidance (Version 2) that

> *"[…] Data collected using static samplers should only be used in the exposure estimation if there is sufficient information provided to demonstrate how they reflect personal exposures or that they provide a conservative estimate of personal exposures […]".*

However, static sampling has an important application in characterising/comparing particular work areas or when exposure levels are very low and personal sampling will not collect sufficient mass to be above the detection limit. Furthermore, it may be required to obtain higher amounts of airborne dust from specific workplaces, for example, if chemical speciation of the analysed elements is required for specific aspects in a risk assessment. This may be the case if a metal has significantly less hazard potential when compared to its oxide form. Due to possible higher air flow (larger pumps could be used) and longer sampling durations than full-shift (see also Section 2.3), sampled mass can be increased in static sampling.

2.2.4.2 Sampling duration

In particular for inhalation monitoring, it is important to define the sampling duration by considering (i) the type of effect (acute or chronic) to which the exposure assessment should refer to and (ii) technical requirements imposed by the exposure situation (e.g. high dust emissions may lead to overload of filters). Often, an exposure situation under REACH applies to an entire work-shift, for which a sampling duration of at least 120 minutes (considered as full-shift representative) should be foreseen if long-term effects are relevant.

When exposure levels are very low, longer sampling periods are required in order to collect enough mass above the detection limit[10]. When an exposure situation is defined for less than 120 minutes, sampling should at least hold for the exposure duration defined.

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[10] The detection limit may be considered a constant (mass) for a given filter (e.g. expressed as mg/filter) when using the same analytical method. When expressing the detection limit as air concentration, the latter is directly correlated with the sampled air volume and therefore decreases with longer sampling durations.

If exposure needs to be compared with reference values for acute effects, sampling may either be conducted for 15 minutes only (as generally considered representative for short-term exposure) in a peak exposure situation or a short-term exposure estimate may be extrapolated from long-term measurements.

Section 3.2.5.3 provides further information on such extrapolation. In addition, MDHS 14/4 (10) provides the following information:

> *"[…] sampling duration should not be longer as reasonably practicable and should reflect actual workplace conditions. Thus, the maximum sampling duration should be an entire shift for comparison with reference values referring to full-shift exposure and short-term samples (i.e. 15 minutes duration) should be taken for comparison with short-term reference values. Task-specific sampling should be performed for the whole duration of the tasks and for 8-hour time-weighted average (TWA) estimation of exposure, the minimum sampling period should be 25 % of the shift."*

There is a possibility that large amounts of dust in the workplace air can cause the sample to become overloaded in a period of time less than the period of interest for the sampling. In such a case, it may be necessary to divide the period of interest of worker sampling into sub-periods. This would result in multiple samples that would be analysed separately and subsequently averaged.

When monitoring exposure to a specific substance, accompanying real-time measurements (i.e. obtained with direct-reading instruments) can help assessing the existence of exposure peaks. However, chemical speciation is not commonly feasible for real-time measurements. Thus, careful interpretation of real-time measurements is required considering potential contribution of additional exposure sources potentially not related to the contaminant of interest.

2.3 Sampling equipment (for monitoring of inhalation exposure)

Substances that are present in workplace atmosphere can potentially be inhaled by workers. Contaminants may be present as gases/vapours (i.e. substances being present as individual molecules) or aerosols of fine liquid droplets and/or airborne dust (including fumes). Whereas gases/vapours are small by nature and thus have the ability to access the entire human respiratory tract (HRT), for aerosols, this ability heavily depends on the size of the droplets or particles actually being present.

Inhalation exposure to metals or metal compounds commonly occurs via dust suspended in workplace atmosphere. For local effects, depending on the specific location in the respiratory tract where the effect occurs, specific fractions of dust may be relevant for exposure assessment. These fractions are defined by the ability of particles to penetrate in certain areas of the human respiratory tract.

Airborne dust cannot be characterised by a single particle size figure since it greatly varies even in a single workplace. Consequently, in terms of particle size, airborne dust is better characterised by a particle size distribution (PSD). According to BS EN 481, such a PSD can be fractionated according to the ability of the particles to penetrate to specific regions of the HRT.

In BS EN 481, the most common fractions are defined as the:

- inhalable fraction (particles that could potentially be inhaled),
- thoracic fraction (particles that could penetrate beyond the larynx) and
- respirable fraction (particles that could penetrate to the unciliated airways).

It is noted that the respirable fraction is a sub-fraction of the thoracic fraction, which is a sub-fraction of the inhalable fraction (e.g. a particle that penetrates to the unciliated airways needs to be inhaled). For each of these fractions, target specifications for sampling instruments are given in BS EN 481 as the percentage (E) of airborne particles of aerodynamic diameter (D) in µm which are to be collected:

- for the inhalable convention as defined by $E_I = 50 \cdot (1 + e^{-0.06 \cdot D})$,
- for the thoracic convention (E_T) as defined by the percentage of E_I given by a cumulated lognormal distribution having a median of 11.64 and a geometric standard deviation (GSD) of 1.5 and
- for the respirable convention (E_R) as defined by the percentage of E_T given by a cumulated lognormal distribution having a median of 4.25 and a GSD of 1.5.

It can be seen in the figure below that E_R is a sub-fraction of E_T being a sub-fraction of E_I:

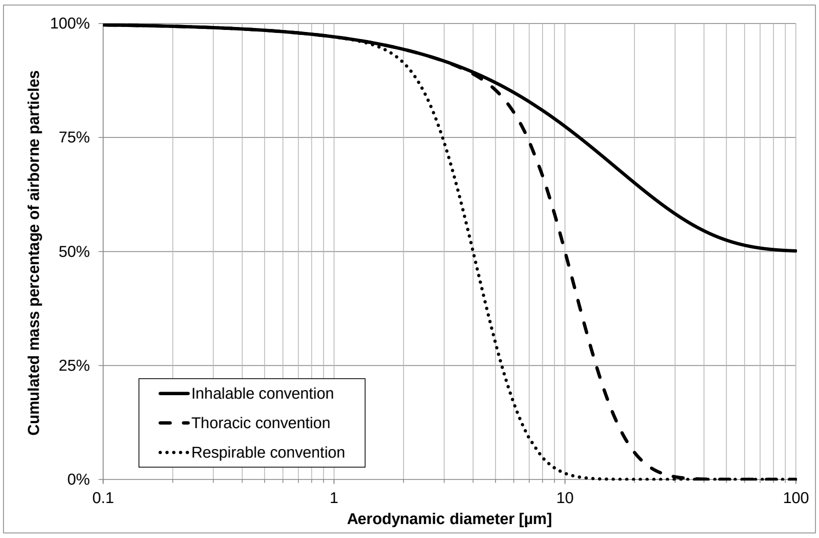

Figure 1: Target specifications of sampling conventions

It is important to note that BS EN 481 also mentions a term “total airborne particles” defined as “All particles surrounded by air in a given volume of air”. This term is however different from the so-called “total fraction”. The latter term is associated with samplers only sampling a sub-fraction of E_I and would therefore underestimate exposure if the inhalable fraction is of concern. It was tried in the past to establish conversion factors converting measurement results for the total fraction into values for the inhalable fraction with varying success and regulatory acceptance. It needs to be noted that such factors can only be established by paired sampling (i.e. simultaneous sampling of the total and the inhalable fraction) with a sufficient number of replicates and that such factors are highly variable between metals and their compounds and workplaces. Further information on the derivation of such factors is given in Section 3.2.2.

Since all commercially available samplers are size-selective, the fraction of dust that could be sampled needs to be considered when selecting samplers. The table below provides an overview of commonly used samplers. Further information can be found, for example, in Vincent (2007) and MDHS 14/3 (including pictures) and MDHS 14/4.

During sampling, special attention should be given to the avoidance of sampling losses due to material adsorbed on sampler walls.

Table 1: Commonly used samplers for monitoring of specific fractions of dust

Name	Manufacturer	Type of sampling*	Required air flow [L/min]	Filter diameter [mm]	Fraction of dust**	Comments
IOM sampler	SKC Ltd.	personal	2	25	I	well validated, commonly used in the UK and other EU countries
GSP 3.5/10	GSA	personal	3.5 / 10	37	I	well validated, commonly used in German speaking countries
FSP 2/10	GSA	personal	2 / 10	37	R	commonly used in German speaking countries
Cyclone	SKC Ltd.	personal	2.2	25 / 37	R	commonly used in the UK and other EU countries
PGP-EA	GSA	personal	3.5	37	I & R	less validated, often used for comparative purposes
Respicon	TSI	personal	3.11	37	I, T, R	less validated, often used for comparative purposes
VC 25	GSA	static	375	150	I or R	very high air flow enabling higher detection limits

*It is noted that all personal samplers can principally also be used for static (area) sampling.
**Inhalable (I), Thoracic (T), Respirable (R)

In addition to the sampler (or the sampling head), the filter material and the sampling pump need to be selected. The filter material should be suitable for the detection of the metal of interest. Sampling pumps should reliably provide a constant air-flow for the measurement duration. It should be acknowledged that each sampler type requires a defined air flow (commonly 2 L/min – 10 L/min for personal sampling and higher flow rates for static sampling, see Table 1). A typical sampling system is schematically represented in the figure below:

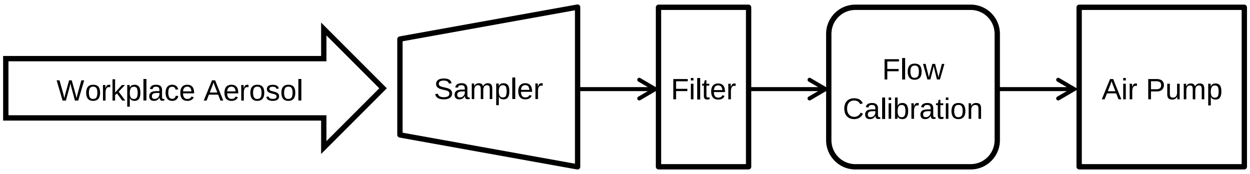

Figure 2: Schematic representation of a sampling system for inhalation exposure

2.4 Quantification of exposure levels from obtained samples

In view of the existence of nuisance dust or general process dust not related to the substance of interest and its potential to bias the substance exposure assessment, the results of the gravimetric analysis of dust deposited on the filters should not be used in isolation when carrying out metal risk assessments. Instead, the metal content should always be quantified by chemical means. In most cases an elemental analysis and recalculation to the substance of interest is sufficient if the reference value to which exposure is to be compared (e.g. DNEL or OEL) is not already given as metal concentration, so that further chemical speciation is often not required.

A number of documents are available providing guidance on the determination of individual substances in monitoring samples. For example, the UK Health and Safety Executive has a website where so-called “Methods for the Determination of Hazardous Substances (MDHS) guidance” are available free of charge: http://www.hse.gov.uk/pubns/mdhs/. On this website, information on the analysis of e.g. lead, cobalt or nickel in air can be found. In addition, several European Standards exist, providing information on measurements of chemical agents in workplace atmospheres (e.g. EN 689). More detailed information may also be available in metal-specific guidance as referenced in Section 4 of this document.

3 Reporting and analysis of sampling results

3.1 Reporting

Regardless of whether monitoring data are to be generated de novo and/or data of historical nature are to be used, the exposure assessor always has to ascertain that a specific level of data quality is achieved and maintained. The assessment of data quality strongly relies on the documentation of the monitoring data. The required information can be divided into:

(i) basic information requirements,
(ii) required contextual information and
(iii) further information not essentially required.

3.1.1 Basic information requirements

Basic information as listed below may most easily be reported together with the monitoring values in spreadsheet format as the information is likely to vary for individual measurements within a data set:

1. Measurement result together with unit – it is noted that individual raw data should be reported, i.e. no aggregated figures (e.g. averages) and no (calculated) time weighted averages (TWA)
2. Handled substance(s) (preferably including information on the handled physical form)
3. Analysed substance
4. Type of monitoring, i.e. personal or static sampling
5. Sampling duration
6. Measured fraction of dust according to BS EN 481, e.g. inhalable, thoracic or respirable (see Section 2.2.3 for further explanation)
7. Sampling date
8. Unique worker ID (can be anonymised) for personal sampling

9. Sampling equipment (sampling head, sampling pump)
10. Method of chemical quantification/analysis
11. Limit of detection (LOD) and limit of quantification (LOQ)
12. Monitored exposure situation (link to contextual information, please see below)

3.1.2 Required contextual information

Contextual information may be given per exposure situation in a questionnaire-like format enabling linking to measurement data (via exposure situation/workplace):

1. Exposure situation including reference to sector/role in the supply chain (e.g. surface coating with metal X)
2. Workplace identification (e.g. plating shop)
3. Conducted process (e.g. surface treatment)
4. Operations/tasks conducted by worker (e.g. sampling and replenishment)
5. Operational conditions (OC):
   a. Frequency and duration of exposure of worker conducting the monitored task(s) (e.g. 120 min twice a shift)
   b. Amount of substance handled (e.g. 5 kg per shift)
   c. Process conditions as relevant (e.g. heated bath 80°C, high current applied)
   d. Level of automation, etc. (e.g. manual)
6. Localised controls
   a. e.g. enclosure during plating
   b. e.g. rim ventilation
   c. etc.
7. Personal protective equipment (PPE) worn by monitored worker[11]

3.1.3 Further information

Further information may help understanding the exposure settings or may enable the use of the monitoring data for the calibration of exposure assessment tools. A selection of such information is provided in Appendix 1 and Appendix 2.

3.2 Data management and data analysis

Data may be most easily arranged in a spreadsheet format enabling quick and correct data manipulation and analysis. The spreadsheet should contain separate columns for the information listed in Section 3.1.1 and list the monitoring results in separate rows. Such data format (flat-file format) facilitates further use of the data set in statistical software packages for advanced data analysis and also makes best use of built-in functionalities of spreadsheet software such as sorting and filtering.

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[11] It is noted that air sampling for occupational exposure assessments is normally conducted outside any respiratory protective equipment (RPE), so that records of RPE used during sampling can be compared with the results of the risk characterisation. Dermal exposure is often measured by skin wiping, i.e. below any potentially worn skin protection. Records of such PPE are therefore required for the exposure assessment and risk characterisation.

3.2.1 Treatment of historical inhalation monitoring data

The use of historical inhalation monitoring data for conducting exposure assessments may be possible in case these data are still relevant for the respective assessment. This decision has to be made based on the available information. In general, basic information requirements (including contextual information) as described in Section 3.1 above have to be considered.

Reasons for excluding historical monitoring data are, e.g.:

- Closing down of a company/site
- Change in the conditions of use
  - Change in product characteristics
  - Change in operational conditions such as availability of localised controls (e.g. LEV)
  - Change in risk managements measures such as personal protective equipment (not relevant for inhalation exposure monitoring but for dermal exposure monitoring and bio-monitoring data)

However, for a sector-wide assessment, it may be beneficial to still include data, for example, from a site that has been closed down if the conditions of use are still relevant for other sites to be assessed. Highlighting again that careful documentation of monitoring data as described above (see Section 3.1) is required so that the similarity of the conditions of use (i.e. of the closed-down site and other sites) can be assessed appropriately.

3.2.2 Treatment of inhalation monitoring data for the total fraction of dust

In 1993, a European standard on the sampling efficiency of air samplers was issued (BS EN 481). According to this standard, samplers may be categorised on the basis of their sampling efficiency of particles of certain size ranges (or fractions - please refer to Section 2.2.3 for further information). In the EU today, the most important fractions are the respirable (RF) and the inhalable fraction (IF). However, older monitoring data, data from the US or some European countries, or data for specific substances may have been obtained for the so-called total fraction (TF). In contrast to the intuitive interpretation of the term, it is important to note that the TF represents a sub-fraction of the IF (please refer to Section 2.3 for further information fractions of dust according to BS EN 481). Thus, if sampling results for the TF were to be compared with a threshold value (e.g. DNEL or OEL) given for the IF, the comparison would lead to an underestimation of risk due to the lower sampling efficiency of the samplers used.

There are 2 cases in which measurements of the TF need to be converted to the IF: firstly, since air monitoring is expensive and time consuming, discarding of existing data should be avoided in an exposure assessment. Secondly, an OEL (or DNEL) may need to be derived for the IF but occupational health studies reporting inhalation exposure according to the TF are to be considered. Obviously, both cases have different requirements in terms of a conversion methodology.

For an exposure assessment, different conversion factors (S) may be relevant depending on the particle size distribution of airborne dust. As a rule of thumb, it can be said that S increase with increasing particle size. Preferentially, S are derived for distinct exposure settings and are applied as such to TF data obtained in these settings individually.

If S are not differentiated for specific workplaces, substantial uncertainty could be introduced in the exposure assessment.

> *<u>For example</u>, in an exposure assessment, TF data may exist for 3 workplaces, namely smelting, grinding and powder handling (packaging). S of 1.2 and 2.7 have been derived for smelting and packaging, respectively. An overall conversion factor of 2 was calculated as an average of the available S. When converting, it is important that the differences in S are acknowledged at the level of the individual workplaces. Consequently, TF data for smelting will be converted to IF by using a factor of 1.2, TF data for packaging by using a factor of 2.7. Obviously, if only the average conversion factor would have been used for all workplaces, exposure in the smelting workplace was over-estimated, whereas exposure in the packaging workplace was under-estimated. How data for which an explicit S was not obtained could be converted (i.e. for the grinding workplace in this example), is explained in the next section.*

If a workplace-specific conversion is rigorously followed, it appears justified to merge such converted data with existing IF databases for the purpose of exposure estimation if all other requirements as described above (i.e. similar conditions of use).

When converting exposure information given as TF (from a health-effect study in workers like a cohort study) to IF exposure information needed for the purpose of threshold-setting (e.g. DNEL), the same principle of workplace-specific conversion applies. However, the consequences of using wrong (or too highly aggregated) S are obviously inverted: using too high S would lead to an under-protection of workers, as the IF exposure levels at which effects were (not) observed would be over-estimated and vice versa.

3.2.2.1 Derivation of conversion factors

Kenny et al (1997) compared sampling efficiencies of the GSP and IOM sampler (both IF) with the efficiency of a 37 mm closed face cassette sampler (CFC; TF). It was found that the samplers for the IF and the CFC were in good agreement for particle sizes up to 10 µm (as would be applicable to fumes). For larger particle sizes (10 µm – 100 µm), it was however found that the CFC considerably under-samples the IF confirming the results of studies by Tsai et al. (1995) and Werner et al. (1996). Vincent (2007) provides a summary of related studies published until 2003 in Table 22.2. In this table, a total of 974 measurements for 27 different workplaces and industries originating from 10 comparative studies are summarised. The 31 values for S (summary ratio of IF and TF) are reported between 0.92 and 3.64.

It is noted that S were calculated by the authors using 1 out of 3 different methods, as listed below:

1. Slope of the regression line (least squares or weighted least squares)
2. Arithmetic mean of the ratio of the individual sampling pairs
3. Ratio of the median of the exposure distribution for IF and TF

It can be seen that all estimates of S are based on the central tendency (or similar measures) of the distribution of the ratios of paired data points but do neither include a measure for the variability nor for the statistical confidence (e.g. related to the number of observations) in S. Such measures would help in assessing the uncertainty associated with using S. Given the differences of S between exposure settings even for the same substance, a measure of variability would also help in identifying whether the assessed situation needs to be further differentiated.

For the derivation of threshold values, EBRC (2015a) suggested an amended scheme originally developed by Werner et al. (1996). This scheme considers the level of knowledge about the workplaces examined in the health effect study (e.g. cohort study) in a tiered approach.

Table 2: Tiered approach for the derivation of conversion factors from total to inhalable fraction for threshold derivation (translated from EBRC, 2015a)

Available information	Tier	Health effect study (HES)	Comparative study	Conversion factor
Information on workplace, task and type of exposure	0	unknown	not relevant	1 (no conversion)
	1	at least type of exposure is known	not available	factors according to Werner et al. (1996), grouped for type of exposure as reported in HES: Dust: 2.5 Mist: 2.0 Hot processes: 1.5 Fumes: 1.0
	2	known	measurements of the total and inhalable fraction at the same workplace paired via the rank of the exposure values (i.e. not necessarily simultaneous measurements) prerequisite: exposure control measures have to be equal or better when monitoring the inhalable fraction	Lower 95 % confidence limit of the arithmetic mean
	3	known	simultaneous measurements of total and inhalable fraction at the same workplace and task	Lower 90 % confidence limit of the arithmetic mean

3.2.2.2 Conversion factors derived and used in the metals' industry

Various conversion factors (S) converting measurement results for the total fraction (TF) into values for the inhalable fraction (IF) were established in the past with varying regulatory acceptance. A summary of established S, how they were derived and how they were used is given in the table below.

Table 3: Conversion factors (S) derived for various metal workplaces (adapted and amended from Vincent (2007))

Metal	Workplaces	S (n)	Method*	Used for		Region of regulatory acceptance	References
				EA	TD		
Al	Welding	1.36 (15)	WLS			Not evaluated	Wilsey et al. (1996)
	Aluminium smelter potroom	2.8 (30)	A	X		NOR	Nordheim (2015)
Be	CuBe processing	2.88 (39)	GM		X	Pending in DE	Kock et al. (2015)
Fe	n.r.	1.39 (54)	A			Not evaluated	Demange et al. (2002)
Mn	n.r.	2 (n.r.)	n.r.		X	EU, DE	DFG (1994)
Ni	Matte grinding	1.8 (11)	WLS	X	X	US	Werner et al. (1999)
	Chlorine leaching	1.7 (14)	WLS				“
	Roasting/smelting	2.3 (12)	WLS				“
	Electrolysis	1.5 (13)	WLS				“
	Alloy production	2.3 (46)	WLS				Tsai et al. (1996b)
	Mining	3.2 (32)	WLS				Tsai et al. (1995)
	Milling	2.7 (21)	WLS				“
	Smelting A	2.8 (23)	WLS				“
	Smelting B	1.7 (35)	WLS				“
	Refining	2.1 (36)	WLS				“
	Electroplating 1	2.0 (21)	WLS				Tsai et al. (1996a)
	Electroplating 2	3.0 (21)	WLS				“
Pb	Smelter	1.77 (151)	WLS			Not evaluated	Spear et al. (1997)
	Battery	1.29 (11)	RM				Vinzents et al. (1995)
V	Abrasive Process	n.d. (1)	LCL		X	Pending in DE	EBRC (2015b)
	Hot Process	X (9)					“
	Material Handling	X (16)					“
	Other	X (9)					“
	Wet Process	X (3)					“

S=Conversion Factor; EA=Exposure Assessment; TD=Threshold Derivation, n.r.=not reported, X=confidential information
*A=Average of the individual paired sample ratios; GM=Geometric Mean of the individual paired sample ratios; LCL=Lower Confidence Limit (90 %) of the arithmetic mean of the individual paired samples ratios; RM=Ratio of Medians of cumulative exposure distributions for TF and IF; WLS=Weighted Least Squares

As can be seen from the table above, reported S-values range from 1.3 to 3.2 for various workplaces and metal industries.

3.2.3 Treatment of values below the limit of detection

At first instance, values below the limit of detection (LOD) should be reported and analysed as LOD. However, if a data set includes many results below the LOD[12], exposure estimates derived from that data set may be biased. This is of particular importance if the LOD is close to the threshold value. In such cases, standard procedures are commonly followed for modifying the LOD to a more relevant value. Dividing the LOD by 2 or √2 is thereby common practice. It is noted that this method should not be applied to datasets containing a high percentage[12] of values below LOD and only with caution for a medium percentage of values below LOD.

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[12] Percentage of LODs in dataset can be categorised as low: ≤ 20 %, medium: 20 % to 50 %, high: 50 % to 80 %, and severe: 80 % to 100 % (Hewett, 2006).

Hewett (2006) describes several methods for treating values below the LOD in occupational exposure assessments:

1. Removal (not recommended)
2. Substitution (by LOD, by LOD/2 or by LOD/√2)
3. Log-probit regression (LPR)
4. Maximum Likelihood Estimation (MLE)

Hewett suggests using substitution only for datasets containing at maximum a medium percentage of values below LOD. In other cases, LPR may be used provided that the sample size is larger than n=15. MLE could be used with even smaller sample sizes.

In cases in which the result is below the limit of quantification (LOQ) but still above LOD, Hewett suggests either using the (unreliable) measured exposure level or to basically apply one of the methods for treatment of values below the LOD as listed above.

However, any modification of a dataset as indicated above should be reported together with the exposure assessment results.

3.2.4 Calculation and use of time weighted averages

If the exposure duration is significantly shorter than full-shift, the calculation of time weighted averages (TWA) may be a useful refinement option for monitoring data. Further information on how such calculations are to be conducted can be found, for example, in EH40/2005. It needs to be noted that the use of TWA in the risk assessment of workers does narrow the applicability of the risk assessment in the following ways:

1. if workers switch between exposure situations (workplaces and/or tasks), TWA are difficult to calculate and introduce further uncertainties in the assessment,
2. exposure duration needs to be restricted in REACH exposure scenarios according to the assumptions made in the calculation of the TWA.

However, any modification of a dataset as indicated above should be reported together with the raw data.

3.2.5 Derivation of exposure estimate

Exposure concentrations vary with time and between workers even if other key exposure factors are kept constant. Reasons for variability may be inter-worker differences in working practices, varying process parameters, differences in the nature of the handled materials (e.g. varying moisture content), etc. In an exposure assessment, it is therefore important to derive an exposure estimate on the basis of repeated measurements for the same exposure situation to account for such variability.

Within the scope of this guidance, any exposure assessment is assumed to relate to an industry sector rather than to individual companies. Consequently, individual measurements are no longer attributable to individuals (although preferably generated by personal monitoring) but instead have to be seen as records of exposure levels which were observed for a specific exposure situation. Consequently, the exposure estimate derived represents a point estimate of potential exposure but is not related to individual workers.

> *For example, in an exposure assessment for an exposure scenario required under REACH, monitoring data from 2 companies may be used. Similarities in conditions of use allow merging of both datasets for a given exposure situation. Both companies have provided 20 data points. Company A has provided monitoring data from 20 workers (all workers monitored once) and company B has provided repeated measurements from 10 workers (all workers monitored twice). Although inferential statistics could help in identifying the contribution of personal behaviour, any derived exposure estimate from the data set of 40 values does no longer relate to an individual worker but instead indicates the likelihood that any worker may experience a certain exposure level in the given exposure situation*[13]*.*

The concept of potential exposure has consequences on the accepted probability that the estimated exposure level exceeds a given (toxicological) threshold. Whereas individual workers should never (or, more precisely, with very low probability) exceed the given threshold, the probability for potential exposure being above the threshold is commonly accepted at higher percentages. International and European standards, technical notes for guidance or technical guidance to legislation indicate probabilities ranging from 5 % to 25 %.

In addition, when it comes to long-term effects (of a population of workers), the corresponding toxicological reference values (e.g. DNEL), commonly consider life-time exposure of workers (often by assuming 40 working years). In other words, the exposure estimate when compared to a chronic DNEL, should be reflective of life-time exposure. Although individual worker’s behaviour is an important exposure factor, it appears unlikely that any single (real) worker would be constantly exposed to upper percentile exposure levels during his or her entire working career.

In contrast to the most likely exposure level (often referred to as “typical” exposure level), estimates at the higher end of the exposure distribution are often called reasonable worst case (RWC) exposure levels. There are various ways how these percentiles can be calculated. Depending on the legal framework for which the assessment is conducted, empirical percentiles, percentiles from parameterised log-normal distributions, confidence intervals of means or similar statistics may be used.

3.2.5.1.1 Descriptive statistics

The exposure estimate as such, is a summary statistic derived from the results of the repeated measurements. The type of the summary statistic used depends on the context in which the exposure assessment is conducted. In risk assessments, the 90th percentile of the data set is commonly accepted representing an estimate for the reasonable worst case exposure level, whereas the median (or 50th percentile) is often used as an estimate for the typical exposure level. Percentiles can be calculated with standard spreadsheet or statistical software, whereas it is noted that different algorithms may be implemented in the various programs.

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[13] From a statistical point of view all data points should be stochastically independent in addition, which is ignored here for the sake of brevity of this example.

According to Hyndman & Fan (1996), 9 different algorithms exist, whereas the general form of:

Q(p)=(1-f)X[i]+fX[i+1]

applies to all types and Q(p) is the pth quantile (percentile) of the data set, i is the integer part and f is the fractional part of the calculated rank statistic. This rank statistic can be calculated as given below:

- Type 1: i.f=np; but f is always set to 0,
- Type 2: i.f=np; but if f=0 then f=0.5 else f=0,
- Type 3: i.f=np; but if f<0.5 then f=0 else f=1,
- Type 4: i.f=np,
- Type 5: i.f=np+0.5,
- Type 6: i.f=(n+1)p,
- Type 7: i.f=(n-1)p+1,
- Type 8: i.f=(n+1/3)p+1/3 and
- Type 9: i.f=(n+1/4)p+3/8

with n representing the number of values.

The selection of the percentile should also consider if sufficient monitoring data are available. The figure below contains a table on data requirements as provided in the R.14 guidance (Version 2). If these data requirements are not met, it is suggested to select higher percentiles (e.g. 95th) to account for higher uncertainties. On the other hand, in cases in which sufficient data are available and the geometric standard deviation (GSD) suggests a high specificity of the data set to the exposure situation to be assessed (for example, GSD < 2 and n > 11), the use of the 75th percentile may be justified.

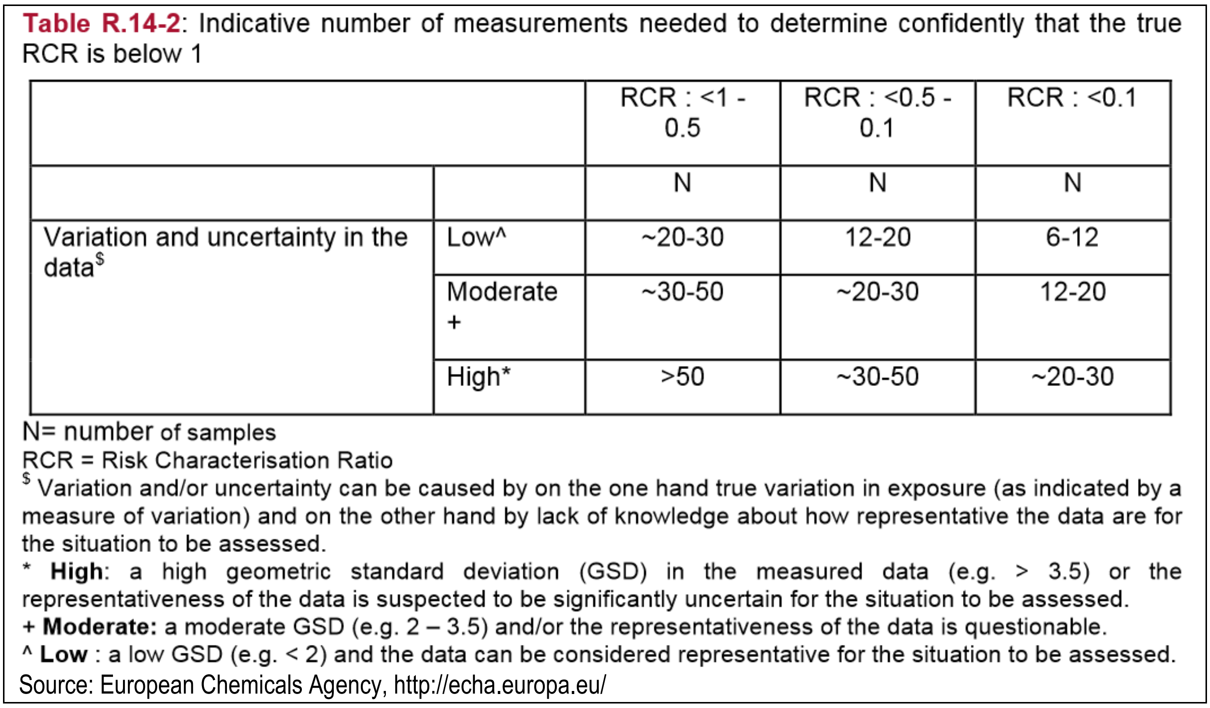

Table R.14-2: Indicative number of measurements needed to determine confidently that the true RCR is below 1

		RCR : <1 - 0.5	RCR : <0.5 - 0.1	RCR : <0.1
		N	N	N
Variation and uncertainty in the data[$]	Low^	~20-30	12-20	6-12
	Moderate +	~30-50	~20-30	12-20
	High*	>50	~30-50	~20-30

N= number of samples

RCR = Risk Characterisation Ratio

[$] Variation and/or uncertainty can be caused by on the one hand true variation in exposure (as indicated by a measure of variation) and on the other hand by lack of knowledge about how representative the data are for the situation to be assessed.

* **High**: a high geometric standard deviation (GSD) in the measured data (e.g. > 3.5) or the representativeness of the data is suspected to be significantly uncertain for the situation to be assessed.

\+ **Moderate:** a moderate GSD (e.g. 2 – 3.5) and/or the representativeness of the data is questionable.

^ **Low** : a low GSD (e.g. < 2) and the data can be considered representative for the situation to be assessed.

Source: European Chemicals Agency, http://echa.europa.eu/

Figure 3: Required number of measurements, excerpt from R.14 guidance, Version 2

In addition to the exposure estimate, the following statistics should always be reported: minimum and maximum value, median value, geometric mean and GSD and the number of values. Whereas dedicated functions are included in spreadsheet software for most of the statistical figures, the GSD requires additional calculation steps. The table below includes the statistical figures suggested to be reported and how they can be derived in commonly used spreadsheet software.

Table 4: How to calculate required summary statistics in spreadsheet software

Summary statistic	**How to calculate in spreadsheet software**
Number of values	=COUNT(values)
Minimum value	=MIN(values)
Maximum value	=MAX(values)
Median value	=MEDIAN(values) or =PERCENTILE(values,0.5)
Geometric mean	=GEOMEAN(values)
Geometric standard deviation	1st step: Calculate natural logarithm for each value by =LN(value) 2nd step: Calculate standard deviation of the calculated natural logarithms of the values =STDEV(ln-values) 3rd step: Calculate e raised to the power of the calculated standard deviation =EXP(STDEV(ln-values))
p^{th} percentile (with $0 \le p \le 100$)* - empirical - parametric (log-normality assumption**)	 =PERCENTILE(values,p/100) =LOGNORM.INV(p/100,LN(GEOMEAN(values)),LN(GSD))

*Two main methods may be used to derive percentiles from a data set: (i) calculation of empirical percentiles or (ii) calculation of percentiles from a fitted (parameterised) distribution. While (i) may be calculated by one out of 9 algorithms (all potentially giving different results, see Hyndman and Fan, 1996), (ii) requires knowledge about the underlying distribution and an efficient handling of values below the limit of detection as these may have a significant impact on the moment estimates (e.g. GM and GSD). For standard applications when the underlying distribution is log-normally distributed and monitoring data are obtained on a representative basis, the use of empirical percentiles may lead to sufficiently accurate results. In these cases, commonly available spreadsheet software can be used because the most appropriate algorithm for the calculation of percentiles for log-normally distributed data is implemented in such programs (see Hyndman, R.J. & Fan, Y. (1996): Sample quantiles in statistical packages, American Statistician, 50, 361-365).

**Such assumption should be examined by a goodness of fit test (e.g. Anderson-Darling or Kolmogorow-Smirnov).

Exposure data are often following a lognormal distribution. As an intrinsic property of such distributions, the probability of sampling values significantly different from typical exposure levels is higher when compared to normal distributions. In practice, exposure assessors have to decide whether such values indeed belong to the same exposure distribution or whether they represent artefacts resulting from mistakes done when sampling and/or chemical analysis was conducted or results were reported and/or interpreted. Although statistical methods exist for identifying such outliers, it is recommended to check the given contextual information and to correct mistakes if possible instead of excluding precious data points from data analysis. Mistakes are often related to wrong units, typos or wrong assignments to exposure situations.

3.2.5.1.2 Inferential statistics

So far, focus was given in this section to the use of descriptive statistics, i.e. statistics that describe the data set as such. However, since exposure data sets are only a sample out of all exposure levels possibly occurring in a given exposure situation, any statistics exclusively based on the data set will be a reflection of the measured exposure levels rather than of all exposure levels possible. In particular, values at the tails of the (real) exposure distribution are difficult to estimate from a sample since the possibility to measure such levels is low (that is the reason why they appear at the tails of the distribution). A small data set will therefore most likely contain only values from the centre of the distribution. Thus, the fewer measurements are available, the more uncertainties are associated with the exposure estimate. This is in particular true when the estimate refers to an upper percentile (of the real exposure distribution).

Inferential statistics can add information to point estimates of exposure by considering the extent and variability of the data set. Such information is normally given as confidence interval indicating a range in which the true (real) value can be found with a given probability (often 95 %). A good overview on statistical methods is, for example, provided in Ignacio et al. (2006). In addition to the methods mentioned there, bootstrapping may be used to derive confidence limits for any given statistic.

3.2.5.2 Exposure assessment under REACH

According to current ECHA guidance on occupational exposure assessment (R.14), the spread of the exposure distribution as expressed by the GSD has to be taken into account when assessing the specificity of the data set to the exposure scenario under investigation: whereas highly specific and robust data sets (i.e. low GSD < 2 and n > 11) could justify the selection of the 75th percentile as an exposure estimate[14], higher GSDs would normally require the selection of higher percentiles, such as the 90th (default) or even the 95th percentile. Additionally, the GSD level is to be taken into account when estimating the required minimum number of data points for an individual exposure assessment: more data points are required with increasing GSD. Further information is provided in Section 3.2.5.1.1.

3.2.5.3 Extrapolation from full-shift exposure levels to short-term exposure levels

Inhalation monitoring data are often made available as full-shift representative sampling results. Thus, when comparing to acute effect levels, additional exposure estimates have to be derived for peak exposure levels. Kumagai & Matsunaga (1994) have investigated into possible factors for such extrapolations. The following table has been generated by considering their findings in a way that only exposure duration of 15 minutes and 95th percentiles for peak exposure estimates are considered relevant:

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[14] In R.14 (Version 3), ECHA suggests using the 75th percentile if monitoring data were obtained under worst-case conditions.

Table 5: Extrapolation factors from full-shift to peak exposure levels

GSD	**Full-shift estimate based on**	
	75th percentile	**90th percentile**
1 - 2	3	2.2
2 – 4	3	2.0
4 – 6	4	1.5
6 – 8	5	1.4
> 8	6	1.4

It is noted that extrapolation factors for full-shift exposure estimates based on higher percentiles than the 90th would be extrapolated by using the factors as given for the 90th percentile on a conservative basis.

> *For example, extrapolation from a full-shift level (P90) of 100 µg/m³ based on data with a GSD of 2.5 to a peak exposure estimate would be done by using a factor of 2 resulting in a peak exposure estimate of 200 µg/m³.*

4 Summary of substance-specific sources of information

Metal, Metal Compound, Type of Exposure	Title	Hyperlink	Further important information*
Aluminium	**NIOSH 7013:** Aluminium and compounds, as Al	http://www.cdc.gov/niosh/docs/2003-154/pdfs/7013.pdf	Analysis by flame AAS. Citation: "Alumina (Al_2O_3) will not be dissolved by this procedure. Lithium borate fusion is necessary to dissolve alumina. The following sample preparation gave quantitative recovery for soluble aluminium compounds."
Aluminium	**OSHA ID-121:** Metal & metalloid particulates in workplace atmospheres (atomic absorption)	https://www.osha.gov/dts/sltc/methods/inorganic/id121/id121.pdf	Analysis by FAAS or AES for 32 elements (Al, Au, K, Sb, Hf, Se, Ba, In, Ag, Bi, Fe, Na, Cd, Pb, Te, Ca, Li, Tl, Cs, Mg, Sn, Cr, Mn, Ti, Co, Mo, Y, Cu, Ni, Zn, Pt, Zr.), but for some elements and/or their substances there are alternate methods or stopgap procedures available.
Aluminium	**OSHA ID-109_SG:** Aluminium oxide in workplace atmospheres	https://www.osha.gov/dts/sltc/methods/inorganic/t-id109sg-pv-02-0110-m/t-id109sg-pv-02-0110-m.pdf	Analysis by AAS.
Aluminium	**IFA 6060:** Aluminium (A-Staub)	http://www.ifa-arbeitsmappedigital.de/6060	
Arsenic and compounds	**MDHS 41/2:** Arsenic and inorganic compounds of arsenic (except arsine) in air.	http://www.hsl.gov.uk/resources/publications/mdhs/mdhs-revisions	"Laboratory method using continuous flow or flow injection analysis hydride generation atomic absorption spectrometry." Evaluated during an indicative rating by the DGUV with an "A".
Arsenic and compounds	**MDHS 91/2:** Metals and metalloids in workplace air by X-ray fluorescence spectrometry	http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs91-2.pdf	Not applicable for As_2O_3. DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/079-04-S-Arsenic.pdf. Analysis by XRF. Evaluated during an indicative rating by the DGUV with an "A".
Arsenic and compounds	**ISO 11041:** Workplace air -- Determination of particulate arsenic and arsenic compounds and arsenic trioxide vapour -- Method by hydride generation and atomic absorption spectrometry	http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=19021	Not applicable for arsenic in the form of metal arsenides. DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/079-01-S-Arsenic.pdf. Analysis by AAS. Evaluated during an indicative rating by the DGUV with an "A".
Arsenic and compounds	**ISO 15202:** Workplace air — Determination of metals and metalloids in airborne particulate matter by inductively coupled plasma atomic emission spectrometry	http://www.iso.org/iso/catalogue_detail.htm?csnumber=51315	Evaluated during an indicative rating by the DGUV with an "A". DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/079-02-S-Arsenic.pdf. Analysis by ICP-AES. Not applicable for As_2O_3.

Metal, Metal Compound, Type of Exposure	**Title**	**Hyperlink**	**Further important information***
Arsine	**NIOSH 6001**: Arsine	http://www.cdc.gov/niosh/docs/2003-154/pdfs/6001.pdf	Analysis by GFAAS. This is an elemental analysis and not compound-specific. Interferences: "Other arsenic compounds (gases or aerosols) may be collected on the sampler and would be erroneously reported as arsine. A cellulose ester filter in front of the charcoal tube may be used to remove aerosols."
Cadmium	**ISO 15202:** Workplace air — Determination of metals and metalloids in airborne particulate matter by inductively coupled plasma atomic emission spectrometry	http://www.iso.org/iso/catalogue_detail.htm?csnumber=51315	Evaluated during an indicative rating by the DGUV with an "A". DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/081-02-S-Cadmium.pdf. Analysis by ICP-AES.
Cadmium	**ISO 11174:** Workplace air - determination of particulate cadmium and cadmium compounds - Flame and electrothermal atomic absorption spectrometric method	http://www.iso.org/iso/catalogue_detail.htm?csnumber=19181	Evaluated during an indicative rating by the DGUV with an "A". DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/081-02-S-Cadmium.pdf. Analysis by ETAAS or FAAS.
Cadmium	**MDHS 10/2:** Cadmium and inorganic compounds of cadmium in air	http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=266B5548B5E4D0845BE8ED237F1DE270?doi=10.1.1.387.1518&rep=rep1&type=pdf	Evaluated during an indicative rating by the DGUV with an "A". "Laboratory method using flame atomic absorption spectrometry or electrothermal atomic absorption spectrometry. It is applicable to the determination of water-soluble cadmium salts and the majority of cadmium-containing materials in industrial use or occurring in workplace air. "
Cadmium	**MDHS 91/2:** Metals and metalloids in workplace air by X-ray fluorescence spectrometry	http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs91-2.pdf	DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/081-04-S-Cadmium.pdf. Analysis by XRF. Evaluated during an indicative rating by the DGUV with an "A".
Chromium	**ISO 15202:** Workplace air — Determination of metals and metalloids in airborne particulate matter by inductively coupled plasma atomic emission spectrometry	http://www.iso.org/iso/catalogue_detail.htm?csnumber=51315	Evaluated during an indicative rating by the DGUV with an "A". DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/082-01-S-Chromium.pdf. Analysis by ICP-AES.
Chromium	**MDHS 12/2:** Chromium and inorganic compounds of chromium in air	http://www.hsl.gov.uk/resources/publications/mdhs/mdhs-revisions	Evaluated during an indicative rating by the DGUV with an "A". DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/082-02-S-Chromium.pdf. "Laboratory method using flame atomic absorption spectrometry."

Metal, Metal Compound, Type of Exposure	Title	Hyperlink	Further important information*
Chromium	**MDHS 91/2:** Metals and metalloids in workplace air by X-ray fluorescence spectrometry	http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs91-2.pdf	DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/082-03-S-Chromium.pdf. Analysis by XRF. Evaluated during an indicative rating by the DGUV with an "A".
Chromium	**MDHS 52/4:** Hexavalent chromium in chromium plating mists	http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs52-4.pdf	The method is suitable for static measurements adjacent to chromium plating baths to aid in assessing efficacy of measures to control emissions of chromium plating mist.
Cobalt	**ISO 15202:** Workplace air — Determination of metals and metalloids in airborne particulate matter by inductively coupled plasma atomic emission spectrometry	http://www.iso.org/iso/catalogue_detail.htm?csnumber=51315	Analysis by ICP-AES. DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/083-01-S-Cobalt.pdf. Evaluated during an indicative rating by the DGUV with an "A".
Cobalt	**HSE 30/2:** Cobalt and cobalt compounds in air. Laboratory method using flame atomic absorption spectrometry.	http://www.hsl.gov.uk/resources/publications/mdhs/mdhs-revisions	Analysis by flame AAS. DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/083-02-S-Cobalt.pdf. Evaluated during an indicative rating by the DGUV with an "A".
Cobalt	**MDHS 91/2:** Metals and metalloids in workplace air by X-ray fluorescence spectrometry	http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs91-2.pdf	Analysis by XRF. DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/083-03-S-Cobalt.pdf. Evaluated during an indicative rating by the DGUV with an "A".
Copper	**MDHS 91/2:** Metals and metalloids in workplace air by X-ray fluorescence spectrometry	http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs91-2.pdf	Analysis by XRF. DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/084-02-S-Copper.pdf. Evaluated during an indicative rating by the DGUV with an "A".
Copper	**ISO 15202:** Workplace air — Determination of metals and metalloids in airborne particulate matter by inductively coupled plasma atomic emission spectrometry	http://www.iso.org/iso/catalogue_detail.htm?csnumber=51315	Analysis by ICP-AES. DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/084-01-S-Copper.pdf. Evaluated during an indicative rating by the DGUV with an "A".
Copper	**OSHA ID-121:** Metal & metalloid particulates in workplace atmospheres (atomic absorption)	https://www.osha.gov/dts/sltc/methods/inorganic/id121/id121.pdf	DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/084-10-S-Copper.pdf. Analysis by FAAS. Evaluated during an indicative rating by the DGUV with an "A".
Generic dust	**IFA 6068:** Alveolengängige Fraktion	http://www.ifa-arbeitsmappedigital.de/6068	DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/125-04-S-Respirable%20aerosol%20fraction.pdf. Evaluated during an indicative rating by the DGUV with an "A". Analysis by gravimetry.

Metal, Metal Compound, Type of Exposure	**Title**	**Hyperlink**	**Further important information***
Generic dust	**IFA 7284:** Einatembare Fraktion	http://www.ifa-arbeitsmappedigital.de/7284	DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/124-04-S-Inhalable%20aerosol%20fraction.pdf. Evaluated during an indicative rating by the DGUV with an "A". Analysis by gravimetry.
Generic dust	**MDHS 95/3:** Measurement of personal exposure of metalworking machine operators to airborne water-mix metalworking fluid	http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs95-3.pdf	"This method describes a procedure for the measurement of time-weighted average concentrations of water-mix metalworking fluid originating from metalworking machine operations. The method is only suitable when the machine sump fluid (liquid circulating in the machine) contains an element which is unlikely to emanate from a source other than the water or metalworking fluid concentrate used to prepare the fluid and this element is present at a high enough concentration to facilitate its use as a marker." Analysis by FAAS, ICP-AES.
Generic dust	**MDHS 14/4:** General methods for sampling and gravimetric analysis of respirable, thoracic and inhalable aerosol	http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs14-4.pdf	Guidance for sampling. DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/124-01-S-Inhalable%20aerosol%20fraction.pdf. Evaluated during an indicative rating by the DGUV with an "A". Analysis by gravimetry.
H_2S	**OSHA 1008:** Hydrogen sulfide	http://www.cdc.gov/niosh/docs/2003-154/pdfs/6013.pdf	Analysis by conductivity detection in Ion chromatography
H_2S	**OSHA ID-141:** Hydrogen Sulfide in Workplace Atmospheres	https://www.osha.gov/dts/sltc/methods/inorganic/id141/id141.html	Analysis by differential pulse chromatography
H_2S	**NIOSH 6013**: Hydrogen sulfide	https://www.cdc.gov/niosh/docs/2003-154/pdfs/6013.pdf	Analysis by conductivity detection in Ion chromatography
Lead	**MDHS 91/2:** Metals and metalloids in workplace air by X-ray fluorescence spectrometry	http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs91-2.pdf	DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/073-04-S-Lead.pdf. Analysis by XRF (Pb L β line). Evaluated during an indicative rating by the DGUV with an "A". Analysis by XRF.
Lead	**ISO 8518:2001:** Workplace air -- Determination of particulate lead and lead compounds -- Flame or electrothermal atomic absorption spectrometric method	http://www.iso.org/iso/catalogue_detail.htm?csnumber=26501	DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/073-01-S-Lead.pdf. Analysis by FAAS and ETAAS. Evaluated during an indicative rating by the DGUV with an "A".

Metal, Metal Compound, Type of Exposure	**Title**	**Hyperlink**	**Further important information***
Lead	**ISO 15202:** Workplace air — Determination of metals and metalloids in airborne particulate matter by inductively coupled plasma atomic emission spectrometry	http://www.iso.org/iso/catalogue_detail.htm?csnumber=51315	Analysis by ICP-AES. DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/073-02-S-Lead.pdf. Evaluated during an indicative rating by the DGUV with an "A".
Manganese	**ISO 15202:** Workplace air — Determination of metals and metalloids in airborne particulate matter by inductively coupled plasma atomic emission spectrometry	http://www.iso.org/iso/catalogue_detail.htm?csnumber=51315	Analysis by ICP-AES. DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/074-01-S-Manganese.pdf. Evaluated during an indicative rating by the DGUV with an "A"
Manganese	**MDHS 91/2:** Metals and metalloids in workplace air by X-ray fluorescence spectrometry	http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs91-2.pdf	Analysis by XRF. DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/074-02-S-Manganese.pdf. Evaluated during an indicative rating by the DGUV with an "A".
Manganese	**OSHA ID-121:** Metal & metalloid particulates in workplace atmospheres (atomic absorption)	https://www.osha.gov/dts/sltc/methods/inorganic/id121/id121.pdf	Analysis by FAAS or AES for 32 elements, but for some elements and/or their substances there are alternate methods or stopgap procedures available. Evaluated during an indicative rating by the DGUV with an "A".
Manganese	Guidance for the collection of inhalable and respirable airborne manganese dust	http://cn.manganese.org/images/uploads/pdf/Measuring_Exposure_in_the_workplace.pdf	Analysis by gravimetry and ICP-AES or AAS.
Mercury	**ISO 17733:** Determination of mercury and inorganic mercury compounds	http://www.iso.org/iso/catalogue_detail.htm?csnumber=31514	"Samples are analysed using either cold vapour atomic absorption spectrometry (CVAAS) or cold vapour atomic fluorescence spectrometry (CVAFS) after acid dissolution of the mercury collected.". DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/075-01-S-Mercury.pdf. Evaluated during an indicative rating by the DGUV with an "A".
Mercury	**MDHS 16/2:** Mercury and its inorganic divalent compounds in air.	http://www.hsl.gov.uk/resources/publications/mdhs/mdhs-revisions	"Laboratory method using Hydrar® diffusive badges or pumped sorbent tubes, acid dissolution and analysis by cold vapour atomic absorption spectrometry or cold vapour atomic fluorescence spectrometry." Evaluated during an indicative rating by the DGUV with an "A".
Nickel	**ISO 15202:** Workplace air — Determination of metals and metalloids in airborne particulate matter by inductively coupled plasma atomic emission spectrometry	http://www.iso.org/iso/catalogue_detail.htm?csnumber=51315	Analysis by ICP-AES. DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/076-01-S-Nickel.pdf. Evaluated during an indicative rating by the DGUV with an "A"

Metal, Metal Compound, Type of Exposure	**Title**	**Hyperlink**	**Further important information***
Nickel	**MDHS 42/2:** Nickel and inorganic compounds of nickel in air (except nickel carbonyl).	http://www.hsl.gov.uk/resources/publications/mdhs/mdhs-revisions	"Laboratory method using flame atomic absorption spectrometry or electrothermal atomic absorption spectrometry." Evaluated during an indicative rating by the DGUV with an "A". DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/076-02-S-Nickel.pdf
Nickel	**MDHS 91/2:** Metals and metalloids in workplace air by X-ray fluorescence spectrometry	http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs91-2.pdf	"This method describes the determination of concentrations of metallic and submetallic elements of atomic number equal to or greater than titanium (Z ≥22) using X-ray fluorescence spectrometry (XRFS)." Evaluated during an indicative rating by the DGUV with an "A". DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/076-03-S-Nickel.pdf
Nickel	Guidance for collection of inhalable and respirable Ni dust	http://www.nickelconsortia.eu/guidance-documents.html	Guidance covers the collection of inhalable and respirable dust.
Platinum	International Platinum Group Metal Association (IPA) - Harmonised Methodology for the Sampling of Platinum in Workplace Atmospheres	http://ipa-news.com/assets/about/IPA-Harmonised-Sampling-Procedure-of-Platinum-at-Workplace.pdf	Guidance focusses on the determination of soluble platinum
Platinum	**OSHA ID-121:** Metal & metalloid particulates in workplace atmospheres (atomic absorption)	https://www.osha.gov/dts/sltc/methods/inorganic/id121/id121.pdf	Analysis by FAAS or AES for 32 elements, but for some elements and/or their substances there are alternate methods or stopgap procedures available.
Platinum	**OSHA ID-130_SG:** Platinum in workplace atmospheres	https://www.osha.gov/dts/sltc/methods/partial/t-id130sg-pv-01-8503-m/t-id130sg-pv-01-8503-m.html	Analysis by GFAAS.
Platinum	**MDHS 46/2:** Platinum metal and soluble platinum compounds in air.	http://www.hsl.gov.uk/resources/publications/mdhs/mdhs-revisions	"Laboratory method using electrothermal atomic absorption spectrometry or inductively coupled plasma-mass spectrometry."
Silver	**OSHA ID-121:** Metal & metalloid particulates in workplace atmospheres (atomic absorption)	https://www.osha.gov/dts/sltc/methods/inorganic/id121/id121.pdf	Analysis by FAAS or AES for 32 elements, but for some elements and/or their substances there are alternate methods or stopgap procedures available. Evaluated during an indicative rating by the DGUV with a "C".
Silver	**ISO 15202:** Workplace air — Determination of metals and metalloids in airborne particulate matter by inductively coupled plasma atomic emission spectrometry	http://www.iso.org/iso/catalogue_detail.htm?csnumber=51315	Analysis by ICP-AES. Rating by the DGUV with a "C".
SO_2	**DFG:** Sulfur dioxide	http://onlinelibrary.wiley.com/doi/10.1002/3527600418.am744609e0008/pdf	Evaluated during an indicative rating by the DGUV with an "A". Analysis by ion chromatography.

Metal, Metal Compound, Type of Exposure	**Title**	**Hyperlink**	**Further important information***
SO_2	**OSHA ID-200:** Sulfur dioxide in workplace atmospheres (impregnated activated beaded carbon)	https://www.osha.gov/dts/sltc/methods/inorganic/id200/id200.html	Analysis by ion chromatography. Evaluated during an indicative rating by the DGUV with an "A".
Tin	**MDHS 91/2:** Metals and metalloids in workplace air by X-ray fluorescence spectrometry	http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs91-2.pdf	Analysis by XRF. DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/077-02-S-Tin.pdf. Evaluated during an indicative rating by the DGUV with an "A".
Tin	**ISO 15202:** Workplace air — Determination of metals and metalloids in airborne particulate matter by inductively coupled plasma atomic emission spectrometry	http://www.iso.org/iso/catalogue_detail.htm?csnumber=51315	Analysis by ICP-AES. DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/077-01-S-Tin.pdf. Evaluated during an indicative rating by the DGUV with an "A".
Tin	**OSHA ID-121:** Metal & metalloid particulates in workplace atmospheres (atomic absorption)	https://www.osha.gov/dts/sltc/methods/inorganic/id121/id121.pdf	DGUV sampling/analysis summary: http://amcaw.ifa.dguv.de/substance/sheets/077-08-S-Tin.pdf. Evaluated during an indicative rating by the DGUV with an "A". Analysis by FAAS.
Tungsten	**OSHA ID-213:** Tungsten and Cobalt in Workplace Atmospheres (ICP Analysis)	https://www.osha.gov/dts/sltc/methods/inorganic/id213/id213.html	Analysis by ICP-AES.
Tungsten	**NIOSH 7074:** Tungsten (soluble and insoluble)	http://www.cdc.gov/niosh/docs/2003-154/pdfs/7074.pdf	Analysis by FAAS.
Vanadium	**NIOSH 7504:** Vanadium oxides	http://www.cdc.gov/niosh/docs/2003-154/pdfs/7504.pdf	Analysis by X-Ray powder diffraction. The method will determine V_2O_5, V_2O_3, and NH_4VO_3 separately on the same sample.
Vanadium	**OSHA ID-185:** Confirmation of Vanadium Pentoxide in Workplace Atmospheres - (Inorganic Method #185)	https://www.osha.gov/dts/sltc/methods/inorganic/id185/id185.html	Analysis by XRF and verification by XRD
Welding fume	**OSHA ID-204:** Quantitative X-Ray Fluorescence Analysis of Workplace Substances	https://www.osha.gov/dts/sltc/methods/inorganic/id204/id204.html	Analysis by XRF
Welding fume	**OSHA ID-213:** Tungsten and Cobalt in Workplace Atmospheres (ICP Analysis)	https://www.osha.gov/dts/sltc/methods/inorganic/id213/id213.html	Analysis by ICP-AES.
Welding fume	**OSHA ID-125G:** Metal and metalloid particulates in workplace atmospheres (ICP analysis)	https://www.osha.gov/dts/sltc/methods/inorganic/id125g/id125g.pdf	Analysis by ICP-AES. Validated for thirteen elements (Be, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, V, and Zn). Expanding the analysis method is dependent on laboratory instrumentation, and element solubility and stability in the matrix used for digestion.

Metal, Metal Compound, Type of Exposure	Title	Hyperlink	Further important information*
Zinc	**NIOSH 7302**: Elements by ICP (Microwave Digestion)	https://www.cdc.gov/niosh/docs/2014-151/pdfs/methods/7302.pdf	Analysis by ICP-AES. Applicability: "This method is for the analysis of metal and nonmetal dust collected on MCE filters in the workplace. The working range varies from element to element." Analyte: Al, Sb, As, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Li, Mg, Mn, Mo, Ni, P, Pt, K, Se, Ag, Na, Sr, Te, Tl, Sn, Ti, V, Y, Zn, Zr.
Zinc	**NIOSH 7304:** Elements by ICP Microwave Digestion	https://www.cdc.gov/niosh/docs/2014-151/pdfs/methods/7304.pdf	Analysis by ICP-AES. Applicability: "The working range of this method varies from element to element. This method is for the analysis of metal and nonmetal dust collected on PVC filters that are also used for gravimetric analysis. This is a simultaneous elemental analysis using a microwave digestion approach to simplify and expedite the analysis. Some elements such as antimony, silver, and tin do not form stable solutions in nitric acid when chloride from the PVC filters is present. In such cases a mixed cellulose ester (MCE) filter is necessary (See NMAM 7302)." Analyte: Al, As, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Li, Mg, Mn, Mo, Ni, P, Pt, K, Se, Na, Sr, Te, Tl, Ti, V, Y, Zn, Zr.
Zinc	**NIOSH 7306**: Elements by cellulosic internal capsule sampler	https://www.cdc.gov/niosh/docs/2014-151/pdfs/methods/7306.pdf	Analysis by ICP-AES. Applicability: "This is simultaneous elemental analysis, not compound specific. Verify that the types of compounds in the samples are soluble with the dissolution procedure selected. Some compounds of these elements require special sample treatment." Analyte: Al, Sb, As, Ba, Be, Cd, Ca, Cr, Co, Cu, In, Fe, La, Pb, Li, Mg, Mn, Mo, Ni, P, K, Se, Ag, Sr, Sn, Te, Tl, Ti, W, V, Y, Zn, Zr.
Zinc	**NIOSH 7502**: Zinc oxide	https://www.cdc.gov/niosh/docs/2014-151/pdfs/methods/7502.pdf	Analysis by X-Ray powder diffraction. Analyte for this method: crystalline zinc oxide; direct analysis on filter.
Zinc	**IFA 8985**: Zinkoxide	http://www.ifa-arbeitsmappedigital.de/8985	

*: Please note that, amongst other kind of information, information on an indicative rating by the DGUV is provided in this column, where available (the complete database is available on: http://amcaw.ifa.dguv.de/WForm09.aspx). However, exclusively sources and methods that have been evaluated with an "A" are included here (except for the substance silver, for which a higher rating than "C" was not available). An "A" has been assigned for methods meeting all of or the most of the major requirements of BS EN 482 (1999). Further information on the rating of analytical methods is available on: http://www.dguv.de/medien/ifa/de/gestis/analytical_methods/3indicative_rating.pdf.

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Appendix 1: Further use of monitoring data for calibration of exposure estimation tools

The development of exposure assessment tools is data hungry by nature. Even for tools dedicated to specific industry sectors, such as the MEASE tool being dedicated to the metals’ sector, a considerable amount of monitoring data is required. This appendix aims at explaining the need for a comprehensive set of contextual information for each measurement when to be used in the calibration of exposure assessment tools.

In exposure estimation tools such as MEASE or ART, occupational exposure is estimated on a conservative basis in consideration of specific tasks that are conducted in combination with present product characteristics, operational conditions (OCs) and risk management measures (RMMs). Examples for tasks are spraying of a substance, transfer of a substance or furnace operations. For these tasks, not only the use of different substances but also the product characteristics of a specific handled substance can lead to varying exposure levels, for example if transfer of massive objects is compared to transfer operations of high dusty powders or if substances with different melting points handled at elevated temperatures are compared. With regard to RMMs, emphasis is placed on present measures at the site and not on personal protective equipment (PPE). That is due to the fact that inhalation exposure measurements usually represent exposure levels outside any respiratory protective equipment (RPE). If applicable, such equipment can be documented and later be taken into account by dividing the exposure level by the so-called assigned protection factor (APF, according to BS EN 529:2005).

In principle, all information that has to be entered in an exposure estimation tool such as MEASE or ART (Advanced Reach Tool) has to be documented during actual inhalation exposure measurements. MEASE is a first tier exposure estimation tool, while ART is a higher tier tool. Correspondingly, some additional information such as information on near-field or far-field exposure (distance of the worker from the emission source) has to be documented.

The use of measured inhalation exposure data to calibrate data for exposure estimation tools would not only help the tool developers but also users of the tool since it is assumed that not every company involved in REACH has measured exposure data for each and every process step. Therefore, a calibrated and validated tool is very helpful for a number of companies. Please refer to Appendix 2 for further details on information requirements for different occupational exposure models.

Appendix 2: Information requirements for data used for the calibration of exposure assessment tools

Information requirements for first tier assessment tools, e.g. MEASE:

- Molecular weight of the handled substance
- Melting point of the handled substance
- Vapour pressure of the handled substance
- Physical form of the handled substance (guidance on physical form is provided in the glossary of MEASE, available on: www.ebrc.de/mease.html)
- Content of the measured substance in the handled product (percentage)
- Information on conducted tasks during measurements (either free text description or assignment of process category according to ECHA Guidance R.12 (available on http://echa.europa.eu/documents/10162/13632/information_requirements_r12_en.pdf))
- Process temperature (for processes at elevated temperature)
- Scale of operation (industrial or professional use within the meaning of REACH)
- Presence, type and efficiency of implemented risk management measures such as enclosures, local exhaust ventilation, suppression techniques, separation of workers

Information requirements for higher tier assessment tools (selection), e.g. ART:

- Involved workplace / process, task description, task duration
- Country
- Near field / far field exposure, distance source to worker > 4 meters
- Process temperature (°C)
- Measurement method
- Amount used
- Containment, localised controls
- Room volume (m^3), ventilation type, ventilation rate (ACH)
- Surface contamination
- Measured substance
- CAS number
- Concentration of substance in product (%)
- Vapour pressure (Pa), boiling temperature (°C), melting point (°C)
- Dustiness, viscosity ($Pa \cdot s$), moisture content
- Etc.