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Standard Guide for Strategies for Surface Sampling of Metals and Metalloids for Worker Protection[1]

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1. Scope

1.1 This guide provides criteria to be used in defining strategies for sampling for metals and metalloids on surfaces for workplace health and safety monitoring or evaluation.

1.2 Guidance provided by this standard is intended for sampling of metals and metalloids on surfaces for subsequent analysis using methods such as atomic spectrometry, mass spectrometry, X-ray fluorescence, or molecular fluorescence. Guidance for evaluation of data after sample analysis is included.

1.3 Sampling for volatile organometallic species (for example, trimethyl tin) is not within the scope of this guide.

1.4 Sampling to determine levels of metals or metalloids on the skin is not within the scope of this guide.

1.5 Sampling for airborne particulate matter is not within the scope of this guide. Guide E1370 provides information on air sampling strategies.

1.6 Where surface sampling is prescribed by law or regulation, this guide is not intended to take the place of any requirements that may be specified in such law or regulation.

1.7 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1356 Terminology Relating to Sampling and Analysis of Atmospheres

D3670 Guide for Determination of Precision and Bias of Methods of Committee D22

D5438 Practice for Collection of Floor Dust for Chemical Analysis

D6399 Guide for Selecting Instruments and Methods for Measuring Air Quality in Aircraft Cabins

D6620 Practice for Asbestos Detection Limit Based on Counts

D6966 Practice for Collection of Settled Dust Samples Using Wipe Sampling Methods for Subsequent Determination of Metals

D7035 Test Method for Determination of Metals and Metalloids in Airborne Particulate Matter by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)

D7144 Practice for Collection of Surface Dust by Microvacuum Sampling for Subsequent Metals Determination

D7202 Test Method for Determination of Beryllium in the Workplace by Extraction and Optical Fluorescence Detection

D7296 Practice for Collection of Settled Dust Samples Using Dry Wipe Sampling Methods for Subsequent Determination of Beryllium and Compounds

D7439 Test Method for Determination of Elements in Airborne Particulate Matter by Inductively Coupled Plasma–Mass Spectrometry

D7440 Practice for Characterizing Uncertainty in Air Quality Measurements

E1216 Practice for Sampling for Particulate Contamination by Tape Lift

E1370 Guide for Air Sampling Strategies for Worker and Workplace Protection

E1402 Guide for Sampling Design

E1542 Terminology Relating to Occupational Health and Safety

E1605 Terminology Relating to Lead in Buildings

E1613 Test Method for Determination of Lead by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES), Flame Atomic Absorption Spectrometry

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

(FAAS), or Graphite Furnace Atomic Absorption Spectrometry (GFAAS) Techniques
E1728 Practice for Collection of Settled Dust Samples Using Wipe Sampling Methods for Subsequent Lead Determination
E1792 Specification for Wipe Sampling Materials for Lead in Surface Dust
E2271 Practice for Clearance Examinations Following Lead Hazard Reduction Activities in Dwellings, and in Other Child-Occupied Facilities

2.2 *ISO and European Standards:*[3]
EN 1540 Workplace Atmospheres—Terminology Flasks
ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories
ISO TR 14294 Workplace Atmospheres—Measurement of dermal exposure–Principles and methods

2.3 *Other Documents:*[4]
40 CFR 745 Lead-Based Paint Poisoning Prevention in Certain Residential Structures

3. Terminology

3.1 For definitions of terms relating to occupational health and safety, see Terminology E1542.

3.2 For definitions of terms relating to sampling and analysis of atmospheres, see Terminology D1356.

3.3 *Definitions:*

3.3.1 *analyte*—designated chemical species to be measured by a monitor or to be identified and quantified by an analyzer. **D6399**

3.3.2 *analytical sensitivity*—ability of an analytical method to detect small amounts of, or small changes in the amount of, the analyte of interest. **(1)**[5]

3.3.3 *analytical specificity*—ability of an analytical method to respond uniquely to the analyte of interest; that is, its ability to measure accurately an analyte, both qualitatively and quantitatively. **(1)**

3.3.3.1 *Discussion*—Important factors in determining analytical specificity include freedom from interference by other components, and good precision and accuracy.

3.3.4 *confidence interval*—range of values that has a specified probability of including the true value of the parameter(s) of an underlying distribution. **(2)**

3.3.5 *data quality objectives (DQOs)*—qualitative and quantitative statements of the overall level of uncertainty that a decision maker is willing to accept in results or decisions derived from environmental data. **D6399**

3.3.5.1 *Discussion*—Minimum DQOs include method detection limit, precision, and bias.

3.3.6 *decision value*—a numerical value used as a boundary in a statistical test to decide between the null hypothesis and the alternative hypothesis. **D6620**

3.3.7 *descriptive statistics*—simple metrics of a sample distribution's characteristics such as central tendency (for example, mean, median) and dispersion (for example, standard deviation, variance, range). **(2)**

3.3.7.1 *Discussion*—Additional examples are the number of samples and the actual fraction of samples above a decision value or a limit value.

3.3.8 *inferential statistics*—parameters used to make estimates about a distribution and underlying population. **(2)**

3.3.9 *limit value*—reference figure for the concentration of a chemical or biological agent. **EN 1540**

3.3.9.1 *Discussion*—As used in this guide, examples of limit values include occupational exposure limits established by regulation, or Threshold Limit Values established by the American Conference of Governmental Industrial Hygienists **(3)**. This should not be confused with analytical limits, such as method detection limit, as defined in Terminology D1356.

3.3.10 *non-parametric statistical inference*—evaluation of a data set using statistical procedures whose validity do not depend on assuming a specified underlying distribution.

3.3.11 *parametric statistical inference*—evaluation of a data set based on assuming a specified underlying statistical model, such as normal or lognormal distributions.

3.3.12 *professional judgment*—application and appropriate use of knowledge gained from formal education, experience, experimentation, inference, and analogy. The capacity of an experienced professional to draw correct inferences from incomplete quantitative data, frequently on the basis of observations, analogy, and intuition. **(2)**

3.3.13 *reporting limit*—value at which reported data are censored.

3.3.13.1 *Discussion*—Values below the reporting limit are typically reported as being less than the reporting limit, such as "<RL" or are reported at the reporting limit with a qualifier, such as "RL (U)". **(4)**

3.3.14 *representative surface*—a surface that is taken to be typical of surface(s) at a given sampling location.

3.3.14.1 *Discussion*—A representative surface may be established as a result of directed sampling (see 7.3.1) or random sampling (see 7.3.2). Thus, "representative" should not be confused with "random."

3.3.15 *sampling location*—a specific area within a sampling site that is subjected to sample collection. **E1728/D6966**

3.3.15.1 *Discussion*—Multiple sampling locations are commonly designated for a single sampling site (see 3.3.16).

3.3.16 *sampling site*—a local geographic area that contains the sampling locations (see 3.3.16). **E1728/D6966**

3.3.16.1 *Discussion*—A sampling site is generally limited to an area that is easily covered by walking.

3.3.17 *stratified sampling*—sampling in which the population to be sampled is first divided into mutually exclusive

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.
[4] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.
[5] The boldface numbers in parentheses refer to a list of references at the end of this standard.

subsets or strata, and independent samples taken within each stratum. **E1402**

3.3.18 *Type I error*—selection, based on a statistical test, of the alternative hypothesis over the null hypothesis when the null hypothesis is, in fact, true; a false positive outcome of a statistical test. **D6620**

3.3.19 *Type II error*—selection, based on a statistical test, of the null hypothesis over the alternative hypothesis when the alternative hypothesis is, in fact, true; a false negative outcome of a statistical test. **D6620**

3.3.20 *upper tolerance limit (UTL)*—– upper confidence limit (with specified confidence level) for a percentile of a distribution. **(2)**

3.3.20.1 *Discussion*—The UTL is the value below which a specified fraction of the population will be found, with a specified level of confidence. For example, the $UTL_{95\ \%,\ 95\ \%}$ is the value for which one would have 95 % confidence that 95 % of the population is below the UTL.

3.3.21 *wipe sample*—sample collected by wiping a representative surface of known area, as determined by Practice E1728, or equivalent method, with an acceptable wipe material as defined in Practice E1792. **40 CFR 745.63, (5)**

4. Significance and Use

4.1 This guide describes approaches which can be used to determine surface sampling strategies before any actual surface sampling occurs. The strategy selection process needs to consider a number of factors, including, but not limited to, purpose for sampling, fitness of the sampling strategy for that purpose, data quality objectives and how the data will be used, ability to execute the selected strategy, and ability of the analytical laboratory (fixed-site or in-field) to analyze the samples once they are collected.

4.2 For the purposes of sampling, and for the materials sampled, surface sampling strategies are matters of choice. Workplace sampling may be performed for single or multiple purposes. Conflicts may arise when a single sampling strategy is expected to satisfy multiple purposes.

4.2.1 Limitations of cost, space, power requirements, equipment, personnel, and analytical methods need to be considered to arrive at an optimum strategy for each purpose.

4.2.2 A strategy intended to satisfy multiple purposes will typically be a compromise among several alternatives, and will typically not be optimal for any one purpose.

4.2.3 The purpose or purposes for sampling should be explicitly stated before a sampling strategy is selected. Good practice, regulatory and legal requirements, cost of the sampling program, and the usefulness of the results may be markedly different for different purposes of sampling.

4.3 This guide is intended for those who are preparing to evaluate a workplace environment by collecting samples of metals or metalloids on surfaces, or who wish to obtain an understanding of what information can be obtained by such sampling.

4.4 *This guide cannot take the place of sound professional judgment in development and execution of any sampling strategy.* In most instances, a strategy based on a standard practice or method will need to be adjusted due to conditions encountered in the field. Documentation of any professional judgments applied to development or execution of a sampling strategy is essential.

4.5 This guide should not be used as a stand-alone document to evaluate any given contaminant or chemical species.

4.6 The surface sampling techniques described in this guide are intended for the determination of metals and metalloids on surfaces, or for the determination of loadings of embedded metallic residues in surface coverings. These techniques may not accurately reflect the transferability or bioavailability of such residues by way of dermal contact or inhalation of resuspended respirable dust.

5. Surface Sampling—General

5.1 Surface sampling results are one of many sources of information about health and safety conditions in a workplace. Information obtained from surface sampling should not be used to the exclusion of other information. Additional sources of information may, as applicable, include air sampling, bioassay and biomonitoring results, clinical observations, quality and process control data, records of facility operations, and material balance studies.

5.2 Agreement among separately obtained sources of information should increase confidence in the interpretation of workplace hazard assessments. Disagreement should be cause for concern, and should result in efforts to determine why the disagreement occurred.

5.3 The factors discussed in Sections 6 through 10 of this guide are interdependent and may need to be applied in an iterative fashion to develop an optimum strategy.

6. Purposes for Surface Sampling

6.1 *General Considerations*—Purposes for surface sampling are based on the following general considerations:

6.1.1 *Drivers for sampling;* that is, the "why" for performing the sampling campaign. Generally, the "why" should fall into one of the following three areas:

6.1.1.1 *Health impact,* or evaluation of the potential health risk from the contaminant or chemical species.

6.1.1.2 *Hazard management,* or evaluation of the source of the contaminant or chemical species, extent of exposure area, and effectiveness of controls.

6.1.1.3 *Hazard compliance,* or evaluation of compliance against regulations or policies.

6.1.2 *Goals* for the sampling campaign, which are based on how the data will be used.

6.1.3 *Data quality objectives,* which define how well the collection and analysis of the samples must be performed.

6.1.4 *Available resources* to conduct the sampling campaign, laboratory analyses, and data evaluation.

6.2 *Examples*—The following are examples of purposes for surface sampling based on the general considerations in 6.1:

6.2.1 *Hazard Identification and Evaluation*—Estimation of one or both of the expected, or maximum, concentrations of

analyte(s) of interest in the workplace. The information obtained is used to evaluate risk, recommend worker protection requirements and to assess the probability of sensitization or hypersensitivity reactions.

6.2.2 *Exposure Assessment for Epidemiology*—Collection of a data base for performing epidemiological studies, when the existence of a health hazard is known or postulated. It is focused on categories of workers, rather than on an individual worker, and requires, within limitations such as those described in 7.1.4, the use of instruments and methods that offer the lowest available analytical reporting limits.

6.2.3 *Facility Characterization*—Determination of the levels of one or more analyte(s) of interest within a facility at an initial or baseline point, during or after process operations, or as part of facility decommissioning.

6.2.4 *Housekeeping*—Determination of the effectiveness of housekeeping actions. Typically, wipe samples are collected both before and after the cleaning procedure used was effective in removing the analyte(s) of interest.

6.2.5 *Selection of Engineering controls*—Determination, for analyte(s) of interest that are not totally contained, the collection or capture efficiencies of control devices necessary to bring specific contaminant concentrations below applicable limits at specific sampling locations, and evaluation of spill clean-up procedure effectiveness.

6.2.6 *Evaluation of Engineering Controls*—Measurement of the quantities of analyte(s) of interest passing or escaping from a control device due to leaks, wear, damage, inadequate maintenance, overloading, or accidents.

6.2.7 *Evaluation of Exposure Pathways*—Measurements used as part of an evaluation of the potential contribution of an analyte of interest on surfaces to worker exposure. Appendix X1 contains additional information on exposure pathways and mass transport processes.

6.2.8 *Selection of Personal Protective Equipment*—Determination of equirements for personal protective equipment in order for a worker to safely inhabit a contaminated or potentially contaminated area for a specific period of time.

6.2.9 *Compliance with Regulations and Standards*—Measurements required to satisfy regulatory or legal requirements, such as 40 CFR 745, or to determine if exposures in the workplace are below occupational exposure limits.

6.2.10 *Source Identification*—Determination of the contribution from each of many potential sources to the presence of analyte(s) of interest, based on the unique characteristics of each of the analyte(s).

6.2.11 *Education and Training*—Sampling used to educate workers in the importance of sound control practices (for example, engineering controls, personal protective equipment, good housekeeping).

6.2.12 *Investigation of Complaints*—Resolution of concerns expressed by workers, management, or other stakeholders.

7. Development of Surface Sampling Plans

7.1 *General Considerations:*

7.1.1 Sampling plans should be fit for the intended purpose or purposes. In general, this means that the outcome of the sampling campaign will be a set of data that meets data quality objectives and can be evaluated to provide the intended information. The intended purpose or purposes should be explicitly stated before evaluating sampling options or selecting a sampling strategy.

7.1.2 Consideration should be given to the expected means by which the material being sampled was deposited on the surface or surfaces being sampled, as this can impact the selected sampling strategy and methods. Conversely, the distribution and level of a material on surfaces may provide information on how the material deposition occurred. Additional guidance on surface deposition mechanisms is provided in Appendix X2.

7.1.3 Principles of good practice, as well as applicable regulatory or legal requirements, should be considered and addressed during development of the sampling plan.

7.1.4 Limitations of the sampling plan should be considered and addressed. These include, but may not be limited to, the following:

7.1.4.1 ability to collect samples at desired sampling locations;

7.1.4.2 resource limitations such as time, cost, equipment, or trained personnel;

7.1.4.3 ability of the analytical laboratory to detect and report the analyte(s) of interest in the given sample matrix, with the required data quality objectives at the anticipated analyte concentration(s); and

7.1.4.4 ability to evaluate the data, especially from a statistical perspective.

7.1.5 Due to one or more of the limitations described in 7.1.4, it may be necessary to develop a single sampling plan intended to accomplish multiple purposes (see 6.2). When this is the case, conflicts may emerge with one or more of the criteria given in 7.2 through 7.5, and compromises will typically be required to optimize the overall sampling strategy. When this occurs, the resulting strategy may not be optimal for any one purpose.

7.1.6 Whether to collect a single sample, or a set of samples, is a key decision. Collection of a set of samples, rather than a single sample, is normally recommended for proper data evaluation. A set of samples, rather than a single sample, is normally required in the following instances:

7.1.6.1 When a comparison of “hot spots” to background locations is needed;

7.1.6.2 When required to meet regulatory requirements, for example, surface cleanliness;

7.1.6.3 When a statistical evaluation of the data is needed.

7.1.7 The following are examples of when a single sample may be appropriate:

7.1.7.1 When physical limitations, such as collecting a sample on a small item or accessibility limitations, prevent the collection of multiple samples.

7.1.7.2 When multiple operations are being performed simultaneously; in this instance, it may not be possible to collect more than one sample per operation.

7.1.8 In cases where sampling is performed in response to an emergency or other urgent situation, the sampling plan typically will be based primarily on professional judgment, since planning time is at a minimum.

7.1.9 The sampling plan should include appropriate quality assurance measures that will provide documentation, throughout the sampling event and subsequent collection and evaluation of data from the samples, that appropriate quality standards have been met.

7.1.10 Documentation of how the sampling plan was developed is of great benefit in the event that issues arise in collecting or analyzing the samples, or in evaluating the data. Considerations include, for example, whether the sampling plan was statistically based, and whether sampling was random, stratified, or a combination of both. Additional guidance is provided in Appendix X3.

7.2 *Number of Samples to Collect:*

7.2.1 When collecting a set of samples, the number of samples to collect is critical. The limitations cited in 7.1.2 through 7.1.5 often affect the number of samples collected. However, these limitations must be balanced against the need to collect a statistically valid number of samples. The number of samples to be collected should typically be the minimum number required to accomplish the intended purpose(s) for sampling.

7.2.2 In general, use of a parametric statistical inference is preferred over a non-parametric statistical inference. However, when a large proportion of the samples are expected to be below the laboratory's reporting limit, a non-parametric statistical inference, which typically calls for larger sample sets, may be required (**6**).

7.2.3 For situations where only a limited number of samples can be collected, and there is some prior knowledge to which professional judgment can be applied, techniques such as Bayesian Decision Analysis (**2**) may be considered.

7.2.4 Additional guidance is provided in Guide E1402.

7.3 *Where to Sample:*

7.3.1 Directed sampling is most appropriate for situations such as, for example, exposure estimation or selection of engineering controls. Such sampling may be based on professional judgment, the need for a representative sampling set, or the need to sample at the sampling locations likely to have the highest levels of the analyte(s) of interest.

7.3.2 Random sampling is most appropriate when performing initial evaluations of analyte(s) of interest in an area or building, or when performing basic research. Use of commercially available software may provide valuable assistance in establishing random sampling locations. Additional guidance on random sampling is found in Practice E2271.

7.3.3 A combination of directed and random approaches, such as stratified sampling, may be appropriate in some instances, based on prior knowledge and professional judgment.

7.3.4 Samples taken for the purpose of regulatory compliance should use the rules of good practice to the maximum extent possible while complying with all applicable regulatory requirements.

7.4 *What to Sample:*

7.4.1 For most purposes, sampling should be performed for the analyte(s) of interest.

7.4.2 In some cases, such as source identification, selection of engineering controls, and evaluation of engineering controls, a marker material other than the analyte(s) of interest may be sampled with greater ease or sensitivity, or both, as long as the marker material concentration is proportional to the source strength of the analyte(s) of interest.

7.5 *When to Sample:*

7.5.1 Sampling should be performed when required by applicable regulations or policies.

7.5.2 Sampling should be performed when there is a probability that one or more individuals may be exposed to significant concentrations of a hazardous material in the settled particulate matter.

7.5.3 Sampling should be performed when it is desired to determine the effectiveness of housekeeping practices; that is, whether cleaning processes are effective. In this instance, sampling both before and after the cleaning activities would normally be performed.

7.5.4 Frequency of sampling should consider the type of operation involved. This may include one or more of the following:

7.5.4.1 Repetitive Operations, such as production lines, where the same, or very similar, operation or cycle of operations is carried out day after day.

7.5.4.2 Non-repetitive or Irregular Operations, such as maintenance or research, where each operation is essentially unique.

7.5.4.3 Enclosed Operations or Processes, whether routine or unusual, where there is little or no human contact with the analyte(s) of interest unless a leak or spill occurs.

8. Selection of Surface Sampling Methods

8.1 The following factors must be considered in the selection of an appropriate surface sampling method:

8.1.1 Nature of surface being sampled, including whether the surface is smooth, rough, porous, fragile, or hard. Some surfaces, such as carpets and cloth upholstery, cannot be properly sampled using wipe sampling techniques.

8.1.2 Amount of settled dust on the surface. Substantial quantities of settled dust may require bulk or vacuum sampling techniques.

8.2 A listing of standards from ASTM International is provided in Table 1. Additional standard methods have been promulgated by the National Institute for Occupational Safety and Health (NIOSH) (**7**)), and the Occupational Safety and Health Administration (OSHA) (**8**). Further information on bulk sampling methods may be found in Special Technical Publication 1282 (**9**) and from the Environmental Protection Agency (EPA) (**10**).

8.3 When utilizing wipe sampling methods, selection of appropriate wipe sampling media is essential. Considerations for selection of a wiping material are as follows:

8.3.1 Suitability for the application.

8.3.2 Suitability for the surface to be wiped.

8.3.3 Compatibility with the analyte(s) of interest.

8.3.4 Suitability for the analytical method which will be used.

TABLE 1 ASTM International Surface Sampling Standards for Metals and Metalloids

Standard	Media/Device	Surfaces
ASTM D6966	Wet wipe	Smooth / Hard
ASTM D7296[A]	Dry wipe	Oily / Fragile
ASTM D7144	Micro-vacuum	Rough / Fragile
ASTM D5438	Vacuum cleaner	Carpets
ASTM E1216	Adhesive tape	Smooth

[A] This practice is specific for beryllium and compounds. Prior to use for other purposes, its fitness for those purposes should be evaluated.

8.4 Wetted wipes, as described in Practice E1792, are preferred over dry wipes. The wetting agent should be selected with consideration for the surface. For example, if the surface is oily, an alcohol may provide better performance as a wetting agent than water (**11**).

8.5 Dry wipes, such as those described for beryllium in Practice D7296, may be preferred for surfaces that would be damaged by or reactive with wetting agents.

8.6 Commonly used wiping materials include paper laboratory filters and pre-packaged wipes. Other materials may be considered for special situations, but their fitness for purpose should be evaluated prior to routine use.

8.7 Measures should be taken to properly preserve samples from the point of collection through transport to the analytical laboratory. Depending on the analyte(s) of interest, these measures may include refrigeration, packing in shock resistant materials, or addition of a fixative or preservative to the sample.

8.8 Measures should be taken to maintain the integrity, security and custody of the samples at all times. This includes documentation of the chain of custody, and may also include provision of a secure receptacle for samples awaiting analysis when not in the documented custody of a responsible person.

8.9 Samples should be carefully handled to avoid cross contamination. That is, the material collected in one sample should not be allowed to spill onto, or contaminate, another sample. This is of particular concern during transfer or shipment of samples, where the opportunities for cross contamination are greatest.

9. Selection of Analytical Methods

9.1 The following items should be considered in the selection of the analytical method that will be used:

9.1.1 *Sensitivity of the Method*—If a screening-level method is fit for purpose, it will typically be faster and less costly than highly-sensitive methods.

9.1.2 *Specificity of the Method*—The selected method should be specific for the analyte(s) of interest, taking into consideration any analytical interferences that may be present.

9.1.3 Need and ability for the method to be performed in a field location as opposed to a fixed laboratory location. Field methods are typically faster, but may be less sensitive than fixed-laboratory methods.

9.1.4 Whether the method will be affected adversely by the sampling media.

9.1.5 Whether the laboratory performing the method needs to be accredited by an appropriate external accrediting organization.

9.2 Table 2 provides examples of ASTM International analysis standards for metals and metalloids. Additional standard methods have been promulgated by agencies such as NIOSH (**7**), OSHA (**8**), and EPA (**12**).

10. Data Evaluation

10.1 *Data Quality Indicators*—An evaluation of key figures of merit, such as those described below, should be performed. These indicators are typically based on the applicable measurement quality objectives (see Appendix X3 for more information). The degree of formality of this review will depend upon the size of the data set (that is, informal for a single datum or small data sets, with more formality for larger data sets). Typical data quality indicators include the following (**13**):

10.1.1 Data representativeness, which refers to the fitness for purpose of the number and location of samples collected and analyzed.

10.1.2 Data completeness, which refers to the proportion of planned samples that are successfully collected and analyzed.

10.1.3 Precision and bias, as described in Guide D3670 for analytical methods, or uncertainty as described in Practice D7440 for sampling and analytical methods.

10.1.4 Analytical sensitivity (3.3.2), which can be nominally represented by the laboratory reporting limit and associated precision.

10.1.5 Analytical specificity (3.3.3).

10.2 Evaluation of individual measurements:

10.2.1 When decisions are to be made based on individual measurements, the decision is typically one of the following binary comparisons:

TABLE 2 ASTM International Analytical Standard Methods for Metals and Metalloids

Standard	Analytical Technique	Analyte(s)	Field, Lab, or Both
ASTM D7035	ICP-AES	Metals/metalloids	Lab
ASTM D7202	Fluorescence	Beryllium	Both
ASTM D7439	ICP-MS	Metals/metalloids	Lab
ASTM E1613	ICP-AES, Atomic Absorption (Flame and Graphite Furnace)	Lead	Lab

10.2.1.1 Qualitative, where the result is expressed as the presence or absence of an analyte (**14, 15**), or as a relative comparison such as the degree of coloration of colorimetric wipes.

10.2.1.2 Semi-quantitative or quantitative, where a numerical result is obtained and compared, with consideration of precision and bias (or uncertainty), against a decision value. Semi-quantitative methods typically have less precision, greater bias, or both, than quantitative methods (**14, 15**).

10.2.2 Acceptable levels should be defined *a priori* for the rates, or likelihoods, of decision errors as described below:

10.2.2.1 For qualitative results, false negatives occur when the analyte is reported to be absent when it is actually present. False positives occur when the analyte is reported to be present when it is actually absent.

10.2.2.2 For semi-quantitative or quantitative results, Type I errors occur when an analyte is reported as being below the decision value when it is actually above the decision value. Type II errors occur when an analyte is reported as being above the decision value when it is actually below the decision value.

10.2.2.3 These likelihoods depend on the actual quantity that is present for an analyte of interest. Acceptable levels of the likelihoods of these errors, as well as evaluations of these likelihoods for a given sampling and analysis scenario, should therefore be phrased in terms of (estimated) likelihoods as functions of true value (concentration, etc.).

10.2.3 To obtain a level of confidence that a reported value is truly below the decision value, calculate the upper confidence limit (UCL), for the desired level of confidence (for example, 95 %), associated with that value and the applicable precision and bias. If the resulting UCL is below the decision value, there is confidence, at the established confidence level (for example, 95 %), that the reported value is in fact below the decision value.

10.3 *Evaluation of Data Sets:*

10.3.1 Evaluation of data sets using descriptive statistics (for example, measures of central tendency and dispersion), when used with professional judgment, may be sufficient when there is not a decision value for comparison, or when most of the data points are well below, or well above, the decision value. Descriptive statistics may also be most appropriate for small data sets, when there are not enough data points to utilize inferential statistics.

10.3.2 Inferential statistics should be used for larger data sets when data points are near, or include, the decision value.

10.3.2.1 Use of a parametric statistical inference is appropriate when the data set can be assumed, or shown through probability plotting or goodness-of-fit testing, to follow a statistical model such as the normal or log-normal distributions adequately for the intended statistical inference.

10.3.2.2 Use of a non-parametric statistical inference is necessary when the data set does not adequately follow a parametric statistical model.

10.3.2.3 If the data set contains a high percentage of censored data (that is, values below the laboratory reporting limit that are shown as "less than" the reporting limit rather than the actual value), use of a parametric statistical inference, such as log-normal, may not be valid, or may be overly conservative (**13**). In these instances, a non-parametric statistical inference may be necessary; however, non-parametric methods may require large data sets, depending on the desired statistical inference.

10.3.2.4 In selected instances, such as facility characterization (see 6.2.3), utilization of data below the laboratory reporting limit, when available, may improve data evaluation (**4, 13**). Appropriate data qualifiers are required to denote that such data are, in fact, below the reporting limit.

10.3.2.5 When evaluating a data set against a limit value, the UTL is frequently compared with the limit value.

10.3.3 Data sets should be evaluated with the assistance of personnel knowledgeable in the appropriate statistical treatment for each data set. This is particularly important for data sets with a high percentage of data below the laboratory's reporting limit. A number of available software programs can assist with proper data evaluation.

10.3.4 Application of professional judgment, including any prior knowledge of the area(s) being sampled, is particularly important for small data sets.

10.3.5 Additional information on descriptive and inferential statistics, as applicable to workplace health and safety sampling, is found in references such as Milz and Mulhausen (**16**). Information in Grams and Davis (**13**) on data quality and reporting, while specific to beryllium, can be generally applied to other metals and metalloids.

11. Quality Assurance

11.1 Conclusion of the sampling event should include verification of the final project package to ensure that the data quality objectives and quality program requirements were followed and properly documented. Section 12 contains a list of required records.

11.2 Proper documentation includes records that are needed by the laboratory, such as chains of custody, and records that are needed from the laboratory, such as results from quality control samples (for example, calibration standards and check standards, blanks, spikes).

11.3 Laboratory quality management systems should meet the requirements of ISO/IEC 17025.

12. Records

12.1 *Log Forms and Notebooks*—Field data related to sample collection shall be documented in a sample log or field notebook. If sample logs are used, then they shall be bound with pre-numbered pages. All entries on sample data forms and field notebook pages shall be made using ink with the signature and date of entry (at least per page). Any entry errors shall be corrected by using only a single line through the incorrect entry (no scratch outs or use of correction fluids), accompanied by the initials of the person making the correction, and the date of the correction. The correct entry shall be annotated next to the error.

12.2 *Electronic Laboratory Notebooks*—If electronic laboratory notebooks, or ELNs, are used in lieu of a field notebook or sample log, procedures shall be implemented to assure the

integrity of the data recorded, including prevention of falsification or other unauthorized changes, and regular backup of data.

12.3 *Sampling Information*—The following information shall be recorded by the person(s) carrying out the sampling, and shall be passed to the person(s) responsible for completing the test report:

12.3.1 A statement to indicate the confidentiality of the information supplied, if appropriate.

12.3.2 Project and client name(s), and client postal address.

12.3.3 General sampling site description and address (if applicable).

12.3.4 Information as to the specific collection protocol used (example: for wipe sampling, use of templates, wiping pattern, etc.).

12.3.5 Information as to the specific type, brand, or both, of sampling medium used, including manufacturer and lot number.

12.3.6 Information on quality control (QC) samples, such as which samples are associated with what group of field blanks.

12.3.7 For each sample collected, including field blanks: an individual and unique sample identifier and date of collection. The individual and unique sample identifier, at a minimum, shall be recorded on the sample container in addition to the field documentation.

12.3.8 For field samples (not including field blanks), record in field documentation (field notebook or sample log form) the dimensions of each area sampled.

12.3.9 For each sample collected: name of person collecting the sample, and specific sampling location information from which the sample was removed.

12.4 *Information Pertinent to Sample Preparation and Analysis*—At a minimum, the following information shall be supplied to the laboratory analyzing the sample(s):

12.4.1 Unique identification for each sample.

12.4.2 Specific type, brand, or both, of sampling medium used.

12.4.3 A listing of the metals, metalloids, or both, to be determined.

12.4.4 Contact information for the person to whom the analysis results shall be returned.

12.4.5 Any special requirements (such as sample preparation method requested).

12.5 *Laboratory Records*—Laboratory records, including electronic records, shall be prepared, controlled and protected in accordance with the requirements of ISO/IEC 17025.

13. Keywords

13.1 occupational health; occupational safety; surface sampling; surface sampling strategies; worker protection; workplace protection

APPENDIXES

(Nonmandatory Information)

X1. EXPOSURE PATHWAYS—ANALYTES ON SURFACES (17)

X1.1 When sampling for analytes of interest from representative work surfaces, it is important to recognize the multiple pathways that may contribute to total-body exposures (that is, Fig. X1.1, adapted from Day et al., 2007). Sources, such as industrial processes, tools, and equipment, may generate metal- or metalloid-containing aerosols in the form of a dust, mist, fume, or combination. A small fraction of these aerosols may be introduced into workers' breathing zones; a larger fraction likely settles onto work surfaces, skin, and clothing. Settled aerosols, particularly those deposited on work surfaces, may be re-entrained into the air, possibly from air movement or mechanical disruption. Additionally, settled aerosols may be transferred to shoes, clothing, or both, and be transported from one area to another within a given workplace environment. Moreover, a fraction of the settled aerosols transferred to workers' hands may be re-distributed to other uncovered areas of the skin, such as the face or the neck. A fraction of the settled aerosols may also be re-introduced into breathing zones. Inadvertent ingestion of metals or metalloids may also represent an important exposure pathway.

X1.2 Guidance for selecting appropriate sampling strategies and methods of collecting and evaluating samples from work surfaces is the purpose of this report. Assessment of exposure pathways may also necessitate evaluating inhalational and dermal exposures through the use of appropriate sampling methods.

X1.3 Additional guidance may be found in Guide E1402, Guide E1370, and ISO TR 14294.

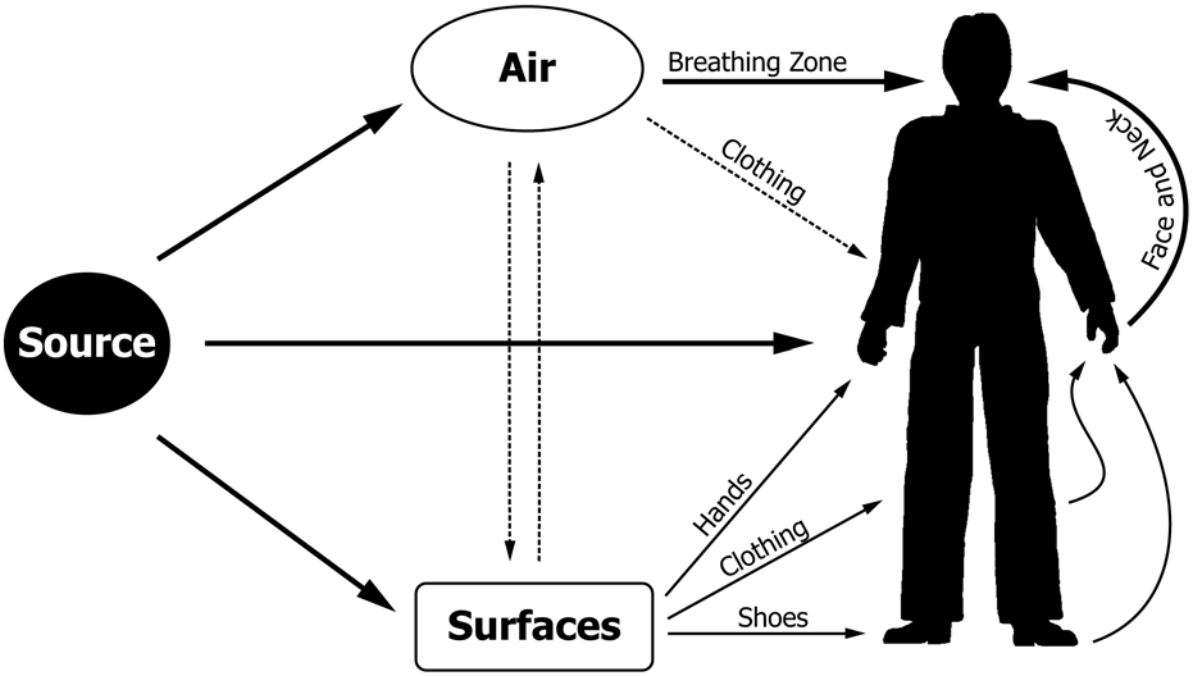

FIG. X1.1 Illustration of Exposure Pathways

X2. SURFACE DEPOSITION MECHANISMS

X2.1 Introduction

X2.1.1 The expected means by which a material was deposited on surfaces can impact the selected sampling strategy and methods. Conversely, the distribution and level of a material on surfaces may provide information on how the material deposition occurred.

X2.1.2 Several surface deposition mechanisms are noted below. Multiple mechanisms may be involved in parallel or in series. For example, a wet cutting operation may deposit material in the immediate vicinity by the splashing of relatively large droplets, and at the same time deposit material over a larger area by the settling of fine mists (parallel deposition). Flooding may result in the deposition of a material on a walking surface via flow transport, which subsequently may be deposited on other surfaces via point-to-point contact with a workers shoe (serial deposition).

X2.1.3 In many cases the deposited material is unwanted and considered contamination or a hazard. Material deposited on surfaces can present a worker exposure risk (see Appendix X1) and a regulatory compliance concern. The material may have physical properties (for example, combustibility, corrosivity, reactivity) that present a risk of fire, explosion, or other damage to facilities. Accumulation of material can also lead to contamination of or damage to product.

X2.2 Point-to-Point

X2.2.1 Deposition by direct mechanical contact with the material; a contaminated item; the hands or feet of workers processing the material or items; or equipment used to handle and transport the material or item. Material deposition tends to be high in spots with little or no material on surrounding surfaces.

X2.2.2 Deposition typically follows a pattern tracking the movement of the material or item, including: the transport pathway (for example, walkways); locations where items are placed (for example, storage shelves); or surfaces that are contacted by workers (for example, handles and knobs).

X2.3 Splash and Spatter

X2.3.1 Deposition by splashing or dripping of a liquid containing a material in solution/suspension (for example, cutting fluid from a machining operation) or the spatter of molten, semi-solid, or tacky material (for example, welding or casting operation).

X2.3.2 Repeated splash and spatter over time can result in a relatively high concentration of material in the splash region that drops off rapidly moving away from the source. Infrequent splash and spatter can result in a very uneven distribution of material in the vicinity of the source.

X2.4 Scatter

X2.4.1 Deposition of material over a surface by mechanical means such as sweeping; tracking via foot or vehicle traffic; winds or strong air currents; loss from conveyer mechanisms; processes that energetically handle materials; etc. Scatter tends to be localized around a source initially, but can result in widespread distribution over time. Scatter tends to be higher in areas that accumulate trash, debris, and clutter.

X2.5 Airstream Impaction

X2.5.1 Particles traveling in an airstream can accumulate on surfaces due to impaction. This may result in an area of high concentration at the point of impact that gradually decreases in level moving away from the point of impaction.

X2.5.2 Sources may include contaminated supply air systems; cooling or process exhaust from equipment; leaks in pressurized product transport or exhaust systems; and string air currents due to HVAC systems or air circulating fans.

X2.6 Flow Transport

X2.6.1 Deposition due to the transport of a material to a surface via the flow of a liquid. This typically involves water or a process fluid (for example, solvents) and is usually unintentional due to leaks and spills. However, poorly planned or executed cleaning processes can also deposit materials on surfaces via flow transport.

X2.6.2 Flooding and drying can result in a relatively high concentration of material on flooded surfaces while nearby, non-flooded surfaces may be free of the material. Also, flooding and drying can result in ring-like patterns of higher concentration similar to contour lines on a map.

X2.7 Settling

X2.7.1 Gravitational settling of airborne particles is the predominate mechanism for the accumulation of material on surfaces at a distance from the source.

X2.7.2 In areas away from other surface deposition mechanisms, settling tends to distribute material relatively evenly over large areas. Over a period of time, high levels can accumulate. Finer particles are more likely to deposit at a greater distance from the source and at higher elevations above the source.

X2.7.3 Fine particles may be carried in HVAC airflows and settle out in rooms or buildings that are physically separated from the source process and a significant distance away.

X3. DATA QUALITY OBJECTIVE PROCESS (18 and 19)

INTRODUCTION

The following is a summary of the Data Quality Objective (DQO) process as defined by Refs (**18 and 19**), with cross-references to applicable sections of this guide. The DQO process outlined below may not be appropriate in all circumstances. Professional judgment should be used in applying this guidance.

X3.1 Define the Purpose

X3.1.1 Develop a concise description of the purpose of the study (see 4.2.3, Section 6, and 7.1.1).

X3.1.2 Develop a conceptual model of the environmental hazard to be investigated.

X3.1.3 Determine resources and limitations (see 4.2.1 and 7.1.4).

X3.2 Identify the Decision(s) or Estimate(s) to Be Made

X3.2.1 Identify principal study question(s) (see Section 6).

X3.2.2 Consider alternative outcomes or actions that can occur upon answering the question(s).

X3.2.3 For decision problems, develop decision statement(s), organize multiple decisions.

X3.2.4 For estimation problems, state what needs to be estimated and key assumptions.

X3.3 Identify the Inputs into the Decision(s)

X3.3.1 Identify the data needed to resolve decisions or produce estimates (see 7.1–7.5).

X3.3.2 Select appropriate sampling and analysis methods for generating the information (see Sections 8 and 9).

X3.4 Define the Boundaries of the Study

X3.4.1 Define the target population of surface areas.

X3.4.2 Determine how many samples to take (see 7.2).

X3.4.3 Determine where to sample (see 7.3).

X3.4.4 Determine what to sample (see 7.4).

X3.4.5 Determine when to sample (see 7.5).

X3.5 Develop the Approach for Analyzing the Data

X3.5.1 Determine the appropriate parameter to use for making decisions.

X3.5.2 Develop the logic for drawing conclusions (see 7.2 and 7.3).

X3.6 Specify Performance Criteria

X3.6.1 Evaluate and select data quality indicators and quality assurance measures (see 10.1 and Section 11).

X3.6.2 For decision problems, examine consequences of making incorrect decisions and place acceptable limits on the likelihood of making decision errors (see 10.2 and 10.3).

X3.6.3 For estimation problems, specify acceptable limits on estimation uncertainty (see 10.2).

X3.7 Optimize the Design for Obtaining Data

X3.7.1 Compile all information and outputs generated in Steps 1 through 6.

X3.7.2 Use this information to identify alternative sampling and analysis designs that are appropriate for your intended use.

X3.7.3 Select and document a design that will yield data that will best achieve your performance or acceptance criteria (see 7.1 and Section 12).

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