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Standard Guide for Sampling Strategies for Heterogeneous Wastes[1]

This standard is issued under the fixed designation D5956; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide is a practical, nonmathematical discussion for heterogeneous waste sampling strategies. This guide is consistent with the particulate material sampling theory, as well as inferential statistics, and may serve as an introduction to the statistical treatment of sampling issues.

1.2 This guide does not provide comprehensive sampling procedures, nor does it serve as a guide to any specification. It is the responsibility of the user to ensure appropriate procedures are used.

1.3 *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. Terminology

2.1 *Definitions of Terms Specific to This Standard:*

2.1.1 *attribute, n*—a quality of samples or a population.

2.1.1.1 *Discussion*—Homogeneity, heterogeneity, and practical homogeneity are population attributes. Representativeness and intersample variance are sample attributes.

2.1.2 *characteristic, n*—a property of items, a sample or population that can be measured, counted, or otherwise observed.

2.1.2.1 *Discussion*—A characteristic of interest may be the cadmium concentration or ignitability of a population.

2.1.3 *component, n*—an easily identified item such as a large crystal, an agglomerate, rod, container, block, glove, piece of wood, or concrete.

2.1.4 *composite sample, n*—a combination of two or more samples.

2.1.4.1 *Discussion*—When compositing samples to detect hot spots or whenever there may be a reason to determine which of the component samples that constitute the composite are the source of the detected contaminant, it can be helpful to composite only portions of the component samples. The remainders of the component samples then can be archived for future reference and analysis. This approach is particularly helpful when sampling is expensive, hazardous, or difficult.

2.1.5 *correlation, n*—the mutual relation of two or more things.

2.1.6 *database, n*—a comprehensive collection of related data organized for quick access.

2.1.6.1 *Discussion*—Database as used in this guide refers to a collection of data generated by the collection and analysis of more than one physical sample.

2.1.7 *data quality objectives (DQO), n*—DQOs are qualitative and quantitative statements derived from the DQO process describing the decision rules and the uncertainties of the decision(s) within the context of the problem(s).

2.1.8 *data quality objective process, n*—a quality management tool based on the scientific method and developed by the U.S. Environmental Protection Agency to facilitate the planning of environmental data collection activities.

2.1.8.1 *Discussion*—The DQO process enables planners to focus their planning efforts by specifying the use of the data (the decision), the decision criteria (action level) and the decision maker's acceptable decision error rates. The products of the DQO process are the DQOs.

2.1.9 *heterogeneity, n*—the condition of the population under which items of the population are not identical with respect to the characteristic of interest.

2.1.10 *homogeneity, n*—the condition of the population under which all items of the population are identical with respect to the characteristic of interest.

2.1.10.1 *Discussion*—Homogeneity is a word that has more than one meaning. In statistics, a population may be considered homogeneous when it has one distribution (for example, if the concentration of lead varies between the different items that constitute a population and the varying concentrations can be described by a single distribution and mean value, then the population would be considered homogeneous). A population containing different strata would not have a single distribution throughout, and in statistics, may be considered to be heterogeneous. The terms *homogeneity* and *heterogeneity* as used in this guide, however, reflect the understanding more common to

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chemists, geologists, and engineers. The terms are used as described in the previous definitions and refer to the similarity or dissimilarity of items that constitute the population. According to this guide, a population that has dissimilar items would be considered heterogeneous regardless of the type of distribution.

2.1.11 *item, n*—a distinct part of a population (for example, microscopic particles, macroscopic particles, and 20-ft long steel beams).

2.1.11.1 *Discussion*—The term *component* defines a subset of items. Components are those items that are easily identified as being different from the remainder of items that constitute the population. The identification of components may facilitate the stratification and sampling of a highly stratified population when the presence of the characteristic of interest is correlated with a specific component.

2.1.12 *population, n*—the totality of items or units under consideration.

2.1.13 *practical homogeneity, n*—the condition of the population under which all items of the population are not identical. For the characteristic of interest, however, the differences between individual physical samples are not measurable or significant relative to project objectives.

2.1.13.1 *Discussion*—For practical purposes, the population is homogeneous.

2.1.14 *random, n*—lack of order or patterns in a population whose items have an equal probability of occurring.

2.1.14.1 *Discussion*—The word *random* is used in two different contexts in this guide. In relation to sampling, random means that all items of a population have an equal probability of being sampled. In relation to the distribution of a population characteristic, random means that the characteristic has an equal probability of occurring in any and all items of the population.

2.1.15 *representative sample, n*—a sample collected in such a manner that it reflects one or more characteristics of interest (as defined by the project objectives) of a population from which it was collected.

2.1.15.1 *Discussion*—A representative sample can be (*1*) a single sample, (*2*) a set of samples, or (*3*) one or more composite samples.

2.1.16 *sample, n*—a portion of material that is taken for testing or for record purposes.

2.1.16.1 *Discussion*—Sample is a term with numerous meanings. The scientist collecting physical samples (for example, from a landfill, drum, or waste pipe) or analyzing samples, considers a sample to be that unit of the population collected and placed in a container. In statistics, a sample is considered to be a subset of the population, and this subset may consist of one or more physical samples. To minimize confusion the term *physical sample* is a reference to the sample held in a sample container or that portion of the population that is subjected to in situ measurements. One or more physical samples, *discrete samples*, or aliquots are combined to form a *composite sample*. The term *sample size* has more than one meaning and may mean different things to the scientist and the statistician. To avoid confusion, terms such as sample mass or sample volume and number of samples are used instead of sample size.

2.1.17 *sample variance, n*—a measure of the dispersion of a set of results. Variance is the sum of the squares of the individual deviations from the sample mean divided by one less than the number of results involved. It may be expressed as $s^2 = \sum (x_i - \bar{x})^2/(n-1)$.

2.1.18 *sampling, n*—obtaining a portion of the material concerned.

2.1.19 *stratum, n*—a subgroup of a population separated in space or time, or both, from the remainder of the population, being internally consistent with respect to a target constituent or property of interest, and different from adjacent portions of the population.

2.1.19.1 *Discussion*—A landfill may display spatially separated strata since old cells may contain different wastes than new cells. A waste pipe may discharge temporally separated strata if night-shift production varies from the day shift. Also, a waste may have a contaminant of interest associated with a particular component in the population, such as lead exclusively associated with a certain particle size.

2.1.19.2 *Discussion*—Highly stratified populations consist of such a large number of strata that it is not practical or effective to employ conventional sampling approaches, nor would the mean concentration of a highly stratified population be a useful predictor (that is, the level of uncertainty is too great) for an individual subset that may be subjected to evaluation, handling, storage, treatment, or disposal. *Highly stratified* is a relative term used to identify certain types of nonrandom heterogeneous populations. Classifying a population according to its level of stratification is relative to the persons planning and performing the sampling, their experience, available equipment, budgets, and sampling objectives. Under one set of circumstances a population could be considered highly stratified, while under a different context the same population may be considered stratified.

2.1.19.3 *Discussion*—The terms *stratum* and *strata* are used in two different contexts in this guide. In relation to the population of interest, *stratum* refers to the actual subgroup of the population (for example, a single truck load of lead-acid batteries dumped in the northeast corner of a landfill cell). In relation to sampling, *stratum* or *strata* refers to the subgroups or divisions of the population as assigned by the sampling team. When assigning sampling strata, the sampling team should maximize the correlation between the boundaries of the assigned sampling strata and the actual strata that exist within the population. To minimize confusion in this guide, those strata assigned by the sampling team will be referred to as *sampling strata*.

3. Significance and Use

3.1 This guide is suitable for sampling heterogeneous wastes.

3.2 The focus of this guidance is on wastes; however, the approach described in this guide may be applicable to non-waste populations, as well.

3.3 Sections 4 – 9 describe a guide for the sampling of heterogeneous waste according to project objectives. Appendix X1 describes an application of the guide to heterogeneous wastes. The user is strongly advised to read Annex A1 prior to reading and employing Sections 4 – 9 of this guide.

3.4 Annex A1 contains an introductory discussion of heterogeneity, stratification, and the relationship of samples and populations.

3.5 This guide is intended for those who manage, design, or implement sampling and analytical plans for the characterization of heterogeneous wastes.

4. Sampling Difficulties

4.1 There are numerous difficulties that can complicate efforts to sample a population. These difficulties can be classified into four general categories:

4.1.1 Population access problems making it difficult to sample all or portions of the population;

4.1.2 Sample collection difficulties due to physical properties of the population (for example, unwieldy large items or high viscosity);

4.1.3 Planning difficulties caused by insufficient knowledge regarding population size, heterogeneity of the contaminant of interest, or item size, or a combination thereof; and,

4.1.4 Budget problems that prevent implementation of a workable, but too costly, sampling design.

4.2 The difficulties included in the first three categories are a function of the physical properties of the population being sampled. The last sampling difficulty category is a function of budget restraints that dictate a less-costly sampling approach that often results in a reduced number of samples and a reduced certainty in the estimates of population characteristics. Budget restraints can make it difficult to balance costs with the levels of confidence needed in decision making. These difficulties may be resolved by changing the objectives or sampling/analytical plans since population attributes or physical properties of the population can seldom be altered. Documents on DQOs discuss a process for balancing budgets with needed levels of confidence.

4.3 Population access and sample collection difficulties often are obvious, and therefore, more likely either to be addressed or the resulting limitations well-documented. A field notebook is likely to describe difficulties in collecting large items or the fact that the center of a waste pile could not be accessed.

4.4 Population size, heterogeneity, and item size have a substantial impact on sampling. The cost and difficulty of accurately sampling a population usually is correlated with the knowledge of these population attributes and characteristics. The least understood population attribute is heterogeneity of the characteristic of interest. If heterogeneity is not known through process knowledge, then some level of preliminary sampling or field analysis is often required prior to sampling design.

4.5 Sampling of any population may be difficult. However, with all other variables being the same, nonrandom heterogeneous populations are usually more difficult to sample. The increased difficulty in sampling nonrandom heterogeneous populations is due to the existence of unidentified or numerous strata, or both. If the existence of strata are not considered when sampling a nonrandom heterogeneous population, the resulting data will average the measured characteristics of the individual strata over the entire population. If the different strata are relatively similar in composition, then the mean characteristic of the population may be a good predictor for portions of the population and will often allow the project-specific objectives to be achieved. As the difference in composition between different strata increases, average population characteristics become less useful in predicting composition or properties of individual portions of the population. In this latter case, when possible, it is advantageous to sample the individual strata separately, and if an overall average of a population characteristic is needed, it can be calculated mathematically using the weighted averages of the sampling stratum means (**1**).

5. Stratification

5.1 Strata can be thought of as different portions of a population, which may be separated in time or space with each portion having internally similar concentrations or properties, which are different from adjacent portions of the population (that is, concentrations/properties are correlated with space, time, component, or source). Fig. 1 is a graphical depiction of different types of strata.

5.1.1 A landfill may display spatially separated strata since old cells may contain different wastes than new cells (stratification over space);

5.1.2 A waste pipe may discharge temporally separated strata if night-shift production varies from the day shift (stratification over time);

5.1.3 Lead-acid batteries will constitute a strata separate from commingled soil if lead is the characteristic of interest (stratification by component); and,

5.1.4 Drums from an inorganic process may constitute a different strata from those co-disposed drums generated by an organic process (a subtype of stratification by component referred to as stratification by source).

5.2 Different strata often are generated by different processes or a significant variant of the same process. The different origins of the strata usually result in a different concentration distribution and mean concentration.

5.3 Highly stratified populations, a type of nonrandom heterogeneous populations, have so many strata that they become difficult to sample and characterize. Classifying a population according to its level of stratification is a relative issue pertaining to the persons planning and performing the sampling, their experience, available equipment, and budgets. Highly stratified populations are such that it is not practical or effective to employ conventional sampling approaches to generate a representative database, nor would the mean concentration of a highly stratified population be a useful predictor (that is, the level of uncertainty is too great) for an individual subset that may be subjected to evaluation, handling, storage, treatment, or disposal.

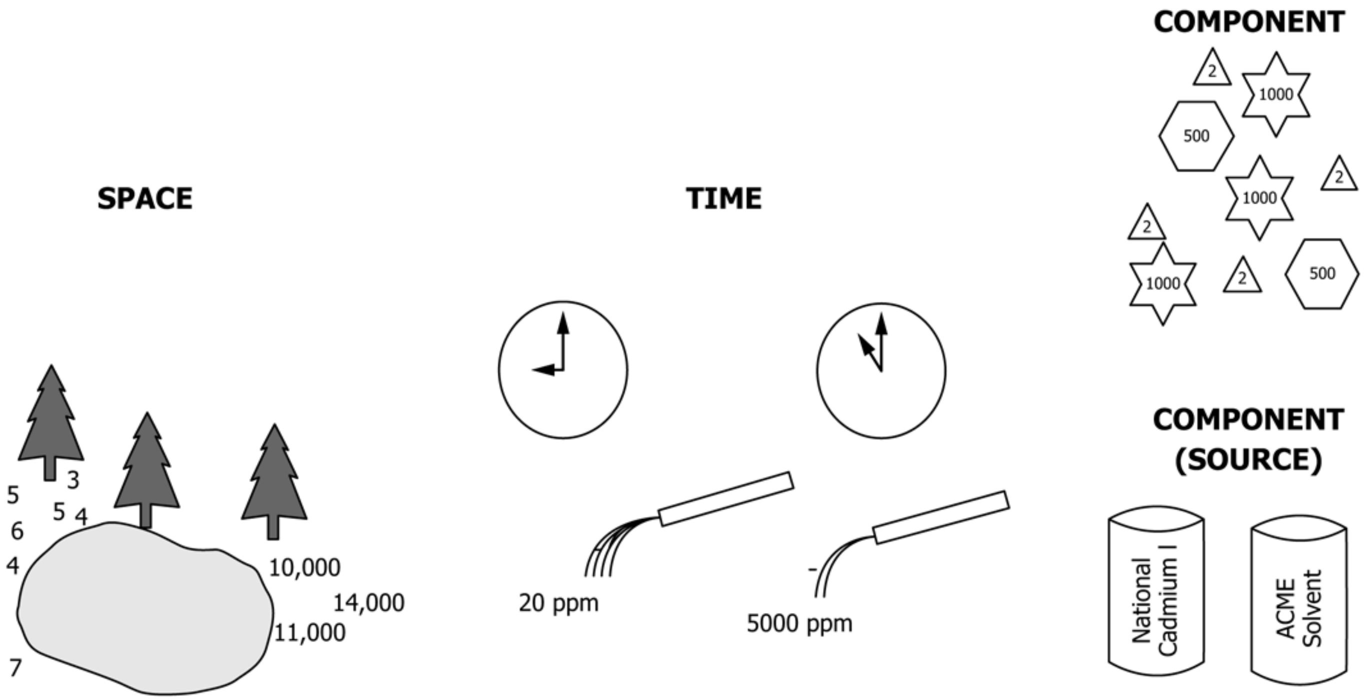

FIG. 1 Types of Stratified Heterogeneous Wastes

NOTE 1—An example of a highly stratified population is a landfill, a candidate for remediation, that is contaminated with the pure and very viscous Aroclor 1260 and with solutions containing varying concentrations of Aroclor 1260. (Aroclor 1260 is viscous and can exist as globules of the pure Aroclor.) The detected concentration of Aroclors in analytical subsamples would reflect a highly stratified population if some samples contained globules of pure 1260, while other samples contained soils that came in contact with solvents containing varying concentrations of 1260. Highly nonrandom heterogeneous populations have numerous strata, each of which contain different distributions of contaminants or item sizes, or both, such that an average value for the population would not be useful in predicting the composition or properties of individual portions of the waste (that is, statistically speaking, the variance and standard error of the mean will be large).

A second and more visually obvious example of a highly stratified population would be a landfill that is filled with unconfined sludge, building debris, laboratory packs, automobile parts, and contained liquids with the constituent of interest having different concentrations in each strata.

5.4 Certain populations do not display any obvious temporal or spatial stratification, yet the distribution of the target characteristic is excessively erratic. For these populations it may be helpful to consider stratification of the population by component. Stratification by component is applied to populations that contain easily identifiable items, such as large crystals or agglomerates, rods, blocks, gloves, pieces of wood, or concrete. Separating a population into sampling strata according to components is useful when a specific kind of component is distributed within the population and when a characteristic of interest is correlated with the component. Stratification by source (for example, organic process waste drums versus inorganic process waste drums) is a type of component stratification. Stratification by component is an important mechanism for understanding the properties of component-heterogeneous populations and for designing appropriate sampling and analytical efforts.

5.4.1 Component strata are not necessarily separated in time or space but are usually intermixed and the properties or composition of the individual components are the basis of stratification. For example, automobile batteries that are mixed in an unrelated waste would be a component that could constitute an individual strata if lead was a target characteristic. If one were to sequester the batteries, they would have a consistent distribution that was different from the rest of the waste.

5.4.2 There is usually no purpose in stratifying by component if different components have similar concentrations of the target characteristic or if the components are small enough such that the different components are represented in the chosen sample size. Even when components have similar composition, however, stratification and use of separate sampling strategies by component may be useful when the different components are so physically different that they cannot all be sampled with the same technique.

5.4.3 A primary objective for employing a stratified sampling strategy is to improve the precision of population parameters such as population means by dividing the population into homogeneous strata. The precision of the population parameters will increase as the sampling strata boundaries, chosen by the sampling team, more closely overlay the actual physical strata that exist within the population.

6. Sampling of Highly Stratified Heterogeneous Wastes

6.1 Sections 6 – 9 focus on the sampling of highly stratified wastes, a type of heterogeneous waste. It is strongly advised that Annex A1 be read and studied prior to the use of this guide. Annex A1 discusses heterogeneity and the relationship between samples and populations.

6.2 Nonrandom heterogeneous wastes contain two or more strata. Stratification of a waste does not always complicate the sampling process; at times, could simplify sampling. Highly stratified populations, however, contain such a large number of strata that they become difficult to sample and characterize. Use of the word *highly* and the classification of wastes according to their level of stratification is a relative issue pertaining to the persons planning and performing the sampling, their experience, available equipment, budgets, and objectives. Highly stratified wastes are such that it is not practical or effective to employ conventional sampling approaches, nor would the mean concentration of a highly stratified waste be a useful predictor (that is, the level of uncertainty is too great) for an individual subset that may be subjected to evaluation, handling, storage, treatment, or disposal.

6.3 A structured approach to sampling planning, such as the DQO process, is a useful approach for the sampling of all wastes regardless of their level of heterogeneity. The first step in characterizing any heterogeneous waste is to gather all available information, such as the need for waste sampling; objectives of waste sampling; pertinent regulations, consent orders, and liabilities; sampling, shipping, laboratory, health, and safety issues; generation, handling, treatment, and storage of the waste; existing analytical data and exacting details on how it was generated; and treatment and disposal alternatives. This information will be used in the planning of the sampling and analytical effort.

6.4 If enough information is available, the planning process may uncover the existence of stratification that may prevent achievement of objectives. If information is lacking, a preliminary sampling/analytical effort may identify and evaluate variability. It is not cost-effective to characterize highly stratified waste by conventional methods, which becomes apparent during the planning process.

6.5 Sections 7 – 9 consider approaches that lessen the impact of stratification and allow for more cost-effective sampling. Some of these approaches require changes in objectives, waste handling or disposal methods, and some require compromises, but all approaches require the above types of information.

6.6 Heterogeneity is a necessary condition for the existence of strata. Wastes can be heterogeneous in particle size or in composition, or both, allowing for the existence of the following:

6.6.1 Strata of different-sized items of similar composition,

6.6.2 Strata of similar-sized items of different composition, and,

6.6.3 Strata of different-sized items and different composition.

7. Strata of Different-Sized Items With Similar Composition

7.1 Wastes having stratification due only to different-sized items will by definition have the same composition or property (that is, for compositional characteristics there is no significant intersample variance and no correlation with space, time, or component) throughout its different strata. The different-sized items may be separated in space or in time. Unless one is attempting to measure particle size for which there is significant intersample variance, this type of population is the simplest of the highly stratified waste types to characterize. All items in these types of wastes usually are generated by the same process (for example, the discussion of silver nitrate powder and crystals in Annex A1), which is the reason for similar composition across all item sizes. These types of wastes, which are compositionally homogeneous and only heterogeneous in item size, are not commonly encountered.

7.2 The complexity of dealing with these types of wastes is in proving that the waste has similar composition across the varying item sizes. This determination can be made by using process knowledge or by sampling the different-sized items to determine if there are significant compositional differences. If the determination is made using knowledge of the waste, it is advisable to perform limited sampling to confirm the determination. The characterization process is greatly simplified once a determination has been made that the waste has similar composition or properties across the various item sizes. The sampling and subsequent analysis can be performed on items that are readily amenable to the sampling and analytical process, and the resulting data can be used to characterize the waste in its entirety.

7.3 It is important to periodically verify the assumption that the different-sized items are composed of materials having the same concentration levels and distributions of the contaminant of interest. This verification is especially important when there are any changes to the waste generation, storage, treatment, or disposal processes. Similarity of composition between items has to be verified for each characteristic of interest. The effect of different-sized items also must be considered when measuring properties, such as the leachability of waste components.

8. Strata of Similar-Sized Items and Different Composition

8.1 Stratification due only to composition or property (that is, there is a correlation of composition or property with time, space, or component) by definition necessitates that item sizes will be consistent across different strata. The strata may be separable in space, time, or by component or source. Identifying and sampling the individual strata may simplify the characterization process. An example of this waste type is a long-term accumulation of wastewater sludge produced by the processing of materials having different composition, through the same waste-generation process (that is, batch-processing that results in waste having uniform item size but different composition from batch to batch).

8.2 Wastes having uniform item size and different composition or properties can be sampled using the same strategy as described for waste containing strata having different composition and different item size (see Section 9).

9. Strata of Different-Sized Items and Different Composition

9.1 Wastes having excessive stratification due to both composition/property and item size (that is, particle size and composition or property, or both, are correlated with time, space, or component) are usually the most difficult wastes to characterize. The difficulty in sampling highly stratified waste can result from:

9.1.1 Various item sizes and waste consistency that makes sampling difficult and conventional sampling approaches cost prohibitive;

9.1.2 Extraordinary concentration gradients between different components or innumerable strata that lead to such excessive variance in the data, that project objectives cannot be achieved; and,

9.1.3 Wastes that exhibit the properties in 9.1.1 and 9.1.2.

9.2 Fig. 2 summarizes an approach to characterizing these types of highly stratified wastes. If a waste is highly stratified, conventional methods of sampling will not allow objectives to be achieved cost-effectively. To sample cost-effectively a highly stratified waste, one must use a nonconventional approach, such as modification of the sampling, sample preparation, or analytical phase of the process. If after modifying the sampling and analysis, the objectives still cannot be achieved in a cost-effective manner, then the original plan of waste handling, treatment, or disposal has to be examined and changed so the waste can be characterized according to new and achievable objectives.

9.3 *Design of the Sampling Approach:*

9.3.1 The first efforts to resolve the difficulty in characterizing a highly stratified waste are focused usually on sampling. A strategy for designing a sampling plan for such highly stratified waste may include the following five steps:

9.3.1.1 Use a planning process such as the DQO process to identify the target characteristics, the population boundaries, the statistic of interest, confidence levels, and other critical issues.

9.3.1.2 Determine whether characteristics of interest are correlated with item size, space, time, components, or sources.

9.3.1.3 Determine if any waste components or strata can be eliminated from consideration during sampling because they do not contribute significantly to the target characteristic.

9.3.1.4 Determine if small items in a stratum represent the stratum, as well as large more difficult to sample items. If yes,

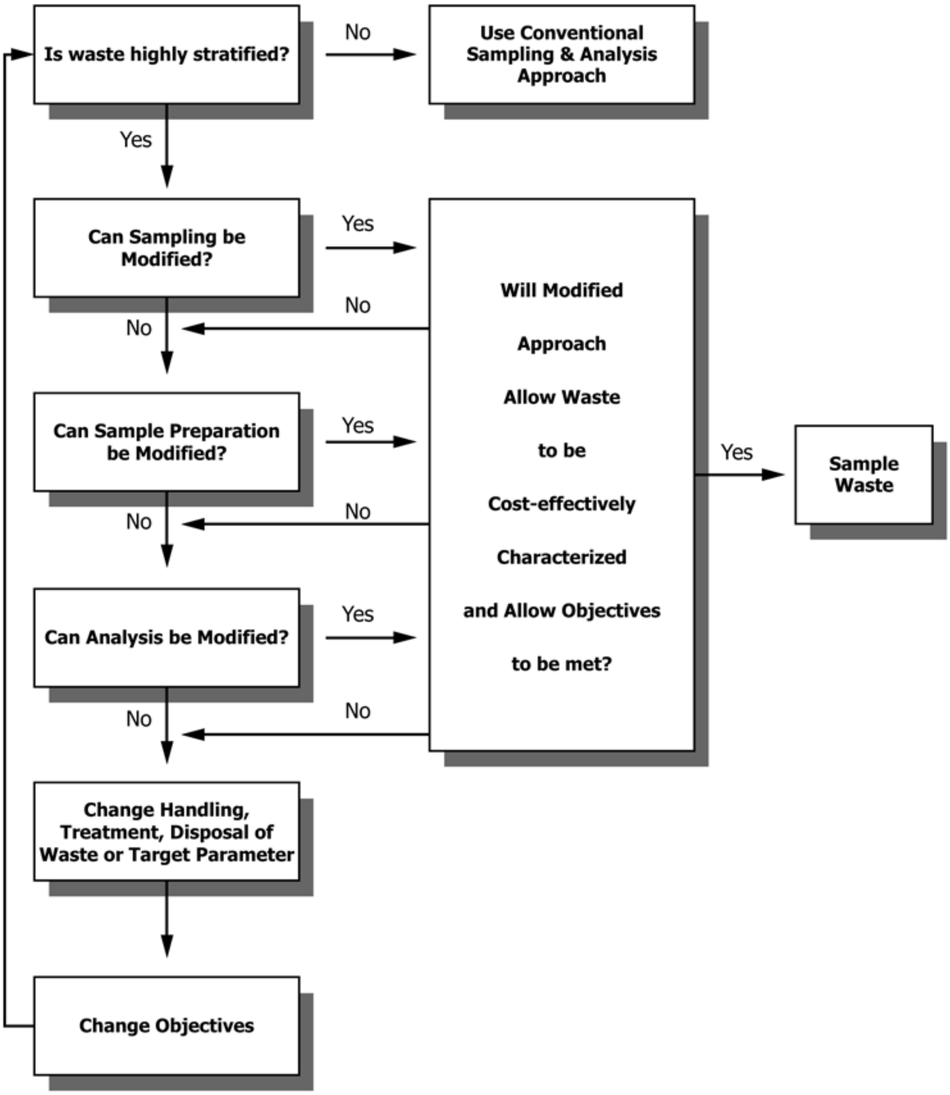

FIG. 2 Approach for the Characterization of Heterogeneous Wastes

sample the smaller items, and only track the volume/mass contribution of the larger items.

9.3.1.5 Determine if the target characteristic is innate or surface adsorbed. Is the target characteristic surface adsorbed, which would allow the material to be sampled representatively by wipe sampling? Can large items be wiped and smaller items extracted, leached, or digested? Can waste be stratified according to impervious and nonimpervious waste and sampled and analyzed accordingly?

9.3.1.6 It is essential that all assumptions (that is, any correlations) be verified at least by knowledge of the waste, and preferably confirmed by sampling and analysis.

9.3.2 All steps taken to optimize sampling should be well-documented.

9.3.3 Appendix X1 contains a case study that applies the above process for optimizing sampling to highly stratified waste. If optimization of sampling design is not sufficient by itself to allow the project objectives to be met cost-effectively, changes to sample preparation or analysis should be considered.

9.4 *Modification of the Sample Preparation Method:*

9.4.1 Information gleaned from the analysis of samples is used to make inferences regarding population attributes. The perception of population homogeneity, as indicated by no significant intersample variance, or the perception of population heterogeneity (that is, as indicated by significant intersample variance) is analytical sample-mass dependent. Usually, the larger the sample mass/volume subjected to analysis the more representative the analytical sample. To improve representativeness of analytical samples and to accommodate large-sized items, conventional sample preparatory methods can be altered. All modifications of methods should be well-documented.

9.4.2 In the laboratory, the term *sample preparation* is commonly meant to include two separate steps: the subsampling of a field sample to generate an analytical sample, and the preparation of the analytical sample for subsequent analysis.

9.4.3 Regarding subsampling, the previously discussed logic for field sampling (see 9.3) is applicable also for the generation of analytical subsamples. Knowledge of concentration distributions within the waste can be used to simplify subsampling by considering the following:

9.4.3.1 Using process knowledge or the results of testing to eliminate any waste components or strata that do not contribute significantly to the concentration of the target compound;

9.4.3.2 Using process knowledge or the results of testing to discriminate against large items, and only select small items when small items represent the waste, as well as the large items; and,

9.4.3.3 Using process knowledge or the results of testing to restrict sampling to surface wipes of larger items and the extraction or digestion of fines if surface contamination is the source of the target characteristic.

9.4.4 If the approaches in 9.4.3.1 – 9.4.3.3 are not applicable to a field sample, the field sample will have to be subjected to particle size reduction (PSR) prior to subsampling or the sample preparation method will have to be modified to accommodate the entire field sample.

NOTE 2—Prior to modifying a sample preparatory method, it is advisable to consult the end user of the data to see if modifications could have any adverse affects. For example, PSR could dramatically alter leaching data.

9.4.5 The PSR is useful for handling field samples, which have items too large for proper representation in an analytical subsample. The intent of PSR is to decrease the maximum item size of the field sample so that the field sample then can be split or subsampled, or both, to generate a representative subsample. The difficulties in applying PSR to waste samples are the following:

9.4.5.1 Not all materials are easily amenable to PSR (for example, stainless steel artifacts);

9.4.5.2 Adequate PSR capabilities and capacities do not exist in all laboratories;

9.4.5.3 The PSR can change the properties of material (for example, leachability);

9.4.5.4 The PSR can be a source of cross-contamination;

9.4.5.5 The PSR often is not applicable to volatile and labile compounds; and,

9.4.5.6 Large mass/volumes may have to be shipped, handled, and disposed.

9.4.6 Modification of sample preparative methods can include the extraction, digestion, or leaching of much larger sample masses than specified. The advantage of this approach is that the characteristic of interest from a larger and more representative sample mass is dissolved into a relative homogeneous extract or digestate that is more suitable for subsampling. This approach is particularly important for volatile organic compounds that may suffer from substantial losses if subjected to PSR. For volatile organic compound analysis, larger portions of the wastes can be subjected to methanol extraction or possibly the entire field sample can be subjected to heated headspace analysis as one sample or as a series of large aliquots, or possibly the entire field sample can be preserved in the field with an equal volume of methanol or methanol/water solution.

9.5 *Modification of Analytical Method:*

9.5.1 The analytical phase of a sampling and analytical program allows another opportunity to simplify the characterization of a highly stratified waste. Examples of different classes of analytical methods are:

9.5.1.1 Screening methods,

9.5.1.2 Portable methods,

9.5.1.3 Field laboratories methods,

9.5.1.4 Nonintrusive methods,

9.5.1.5 Nondestructive methods,

9.5.1.6 Innovative methods, and

9.5.1.7 Fixed laboratory methods.

9.5.2 Screening, portable, and field laboratory methods have the distinct advantage that they allow for the cost-effective analysis of more samples. These methods generate more data, making it easier to detect correlations between concentration levels and waste strata or components. Also, some screening methods may analyze a larger sample volume than what is traditionally analyzed in a fixed laboratory.

9.5.3 Nonintrusive methods (for example, geophysical methods) can be useful when there are health and safety issues regarding exposure to the waste. These methods also may be used to evaluate large-volume wastes qualitatively or semi-quantitatively.

9.5.4 Nondestructive methods are useful in that the integrity of the samples is maintained for additional analyses or evidence, or both.

9.5.5 Innovative methods may provide more cost-effective or timely results or improve sensitivity or accommodate larger and more representative sample sizes.

9.5.6 Fixed laboratory methods usually have the advantage of regulatory approval, established quality assurance/quality control requirements and often greater sensitivity than that achievable by screening, portable, or field laboratory methods.

9.6 *Modification of the Waste Handling, Treatment, Disposal Plan:*

9.6.1 If modifications to sampling, sample preparation, and analysis are not appropriate for a given waste, or are appropriate but still do not allow the objectives to be met cost-effectively, then the reasoning behind the original program must be reconsidered. It may be possible to achieve the program objectives by means of an alternative approach. For example, a change in waste treatment, handling, or disposal technologies may require analysis for different characteristics or may allow for simplified sampling. Alternatively, the waste population could be defined differently by employing smaller remediation or exposure units that would be sampled separately as opposed to characterizing the entire population. The need behind the waste characterization objectives has to be examined and an approach for simplifying the characterization process devised. This process is addressed in the optimization step of the planning process.

9.6.2 For example, consider a hypothetical waste that must be evaluated prior to waste disposal to determine if it is hazardous. An initial attempt to characterize the waste failed to meet the objective, indicated that the waste was highly stratified, and proved that portions of the waste are hazardous. After reviewing this preliminary information and the costs to attempt a defensible characterization of the waste, it could be decided that it is resource and cost-effective to consider all the waste hazardous and treat it as a hazardous waste by incineration. Under this scenario, the sampling and analytical requirements change, requiring simplified testing for general characteristics prior to incineration, and more comprehensive analysis of the less heterogeneous and more easily sampled incinerator ash to determine if it is within compliance.

9.7 *Changing Objectives*—If the project objectives are not met and none of the strategies can be changed or modified, the objectives need to be reconsidered. After changing the objectives, the sampling and analysis plans also should be adjusted. These iterations will continue until the project objectives can be met.

10. Keywords

10.1 analysis; heterogeneity; homogeneity; nonrandom; populations; random; sample preparation; samples; sampling; strata; stratified; stratum

ANNEX

(Mandatory Information)

A1. DISCUSSION OF HETEROGENEITY AND STRATIFICATION OF WASTES AND RELATIONSHIP OF SAMPLES AND POPULATIONS

A1.1 *Introduction*—This annex contains a practical non-mathematical discussion of issues pertinent to heterogeneous waste sampling. The discussion deals with heterogeneity, stratification, and the relationship of samples and populations in sampling design. It is consistent with sampling theory and statistics and may serve as an introduction to the statistical treatment of sampling issues (see Refs **2-10**).[2] The content of this annex is applicable to the sampling of wastes regardless of their degree of heterogeneity.

A1.2 *Population Attributes:*

A1.2.1 A population is the total collection of items to be studied. Theoretically, the classification of a population as being homogeneous or heterogeneous is straightforward. If all of the items in the population are identical, then the population is homogeneous. If one or more of the items are dissimilar, the population is heterogeneous. Theoretical homogeneity, the equivalent to nonheterogeneity, is a unique state of absolute uniformity for all items in the population while heterogeneity is a variable attribute that can range from a population, which is almost homogeneous (that is, homogeneous for applied purposes) to a population that displays dissimilarity between all items of the population.

A1.2.2 According to the theoretical definition for homogeneity, virtually all real-world populations would be heterogeneous. From a practical perspective, however, as the level of heterogeneity approaches the state of homogeneity, populations can be considered homogeneous for applied purposes. References to the homogeneity of a population are usually made in light of this applied meaning, that is, for practical purposes, the population is homogeneous (practical homogeneity).

A1.2.3 The attributes of homogeneity and heterogeneity are relative. Heterogeneity and homogeneity are a function of the specified chemical constituent, property, particle size, visual appearance, sampling objectives, and the sample mass/volume.

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[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

The same population can be homogeneous with regards to one constituent or property, and at the same time be heterogeneous with regards to another constituent or property.

A1.2.3.1 Consider a nonrandom mixture of silver nitrate, some of which is a powder and the remainder is in the form of large crystals (see Fig. A1.1). The population is heterogeneous when considering particle size or homogeneous when silver content is of interest.

A1.2.3.2 Following comprehensive emission spectroscopic and titrimetric analyses of uranium metal, a chemist may find the population to be homogeneous while the nuclear chemist analyzing for U^{235} and U^{238} would find the same population to be isotopically heterogeneous (see Fig. A1.2).

A1.2.3.3 Decisions regarding heterogeneity also can be a function of the analytical method used to process samples. If one method (AAS-graphite furnace atomic absorption spectroscopy) is more sensitive and has method detection limits (MDL) that are lower than the other (X-ray fluorescence field screening), what was originally thought to be a homogeneous waste may be found to be a heterogeneous waste (see Fig. A1.3).

A1.2.4 Two population attributes are the causative factors for heterogeneity. The primary attribute is referred to as compositional heterogeneity, and the secondary attribute is distributional heterogeneity.

A1.2.4.1 Compositional heterogeneity occurs when the concentration of the targeted constituent or targeted property varies from item to item. This compositional or property difference between items is a requisite for a heterogeneous population, that is, dissimilar items must be present for heterogeneity to exist.

A1.2.4.2 Distributional heterogeneity results from differences in the spatial distribution of dissimilar items resulting in microscopic or macroscopic concentration gradients or property gradients, or both. Compositional heterogeneity is a necessary condition for the existence of distributional heterogeneity. Distributional heterogeneity is a population attribute, and if a population is defined differently (that is, change the population boundaries), the distributional heterogeneity for the expanded or smaller population may differ.

A1.2.5 Compositional and distributional heterogeneity are the underlying causes for the more commonly understood types of random heterogeneity and nonrandom heterogeneity. Random and nonrandom are the terms that will be used in the remainder of this guide to describe the different types of heterogeneity. The introduction of compositional and distributional heterogeneity is to assist those who may want to investigate further the particulate material sampling theory.

A1.2.5.1 Random heterogeneity is that type of heterogeneity that occurs when dissimilar items are randomly distributed throughout the population.

A1.2.5.2 Nonrandom heterogeneity is that type of heterogeneity that occurs when dissimilar items in the population are nonrandomly distributed. In a nonrandom heterogeneous population, similar items or similar concentrations are grouped into strata. This type of population, also is referred to as a *stratified population*. The terms *stratified population* and *nonrandom heterogeneous populations* are interchangeable. Strata are separated from other strata by time or space or correlated with different components or waste sources. This guidance focuses on sampling strategies for a particular type of stratified waste referred to as *highly stratified*.

A1.3 *Physical Sample Attributes:*

A1.3.1 To characterize a population, it must be subjected to evaluation. The population can be characterized with great certainty if all population elements are evaluated for the characteristic of interest. Populations, however, are usually so large that the entire population cannot be subjected to evaluation. Practically and economically it makes more sense to

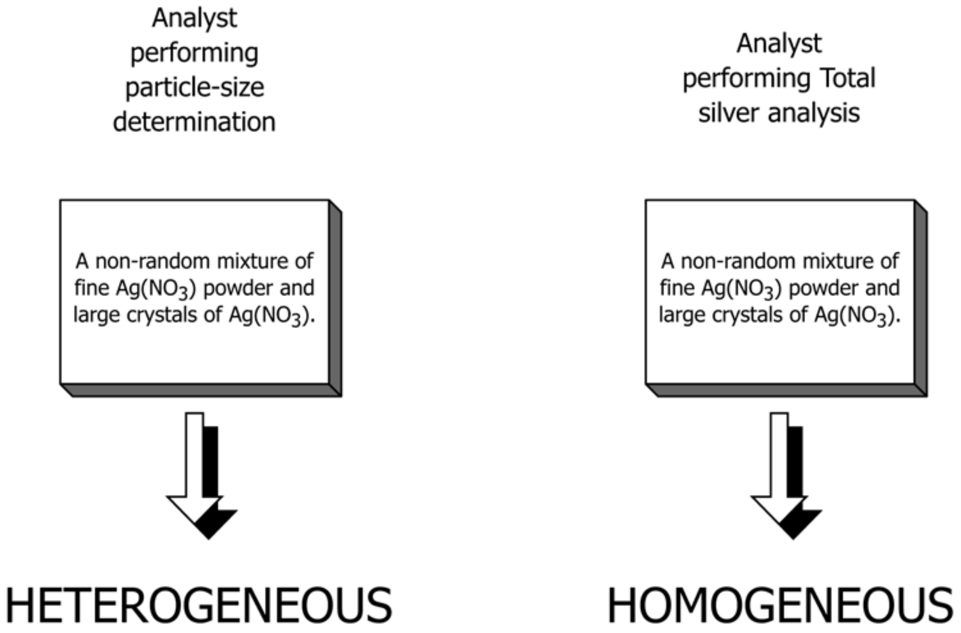


FIG. A1.1 Heterogeneity Relative to Objectives

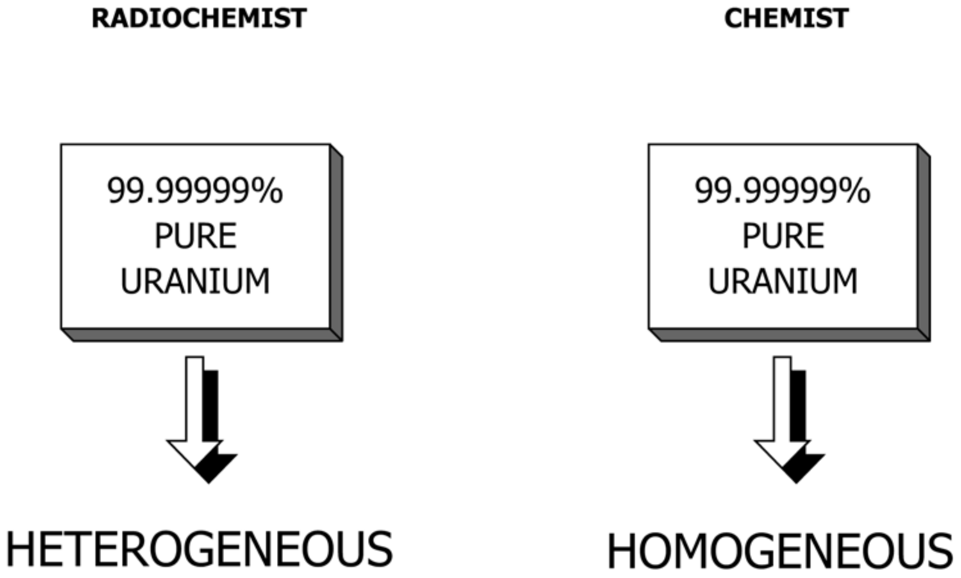


FIG. A1.2 Heterogeneity Relative to Perspective

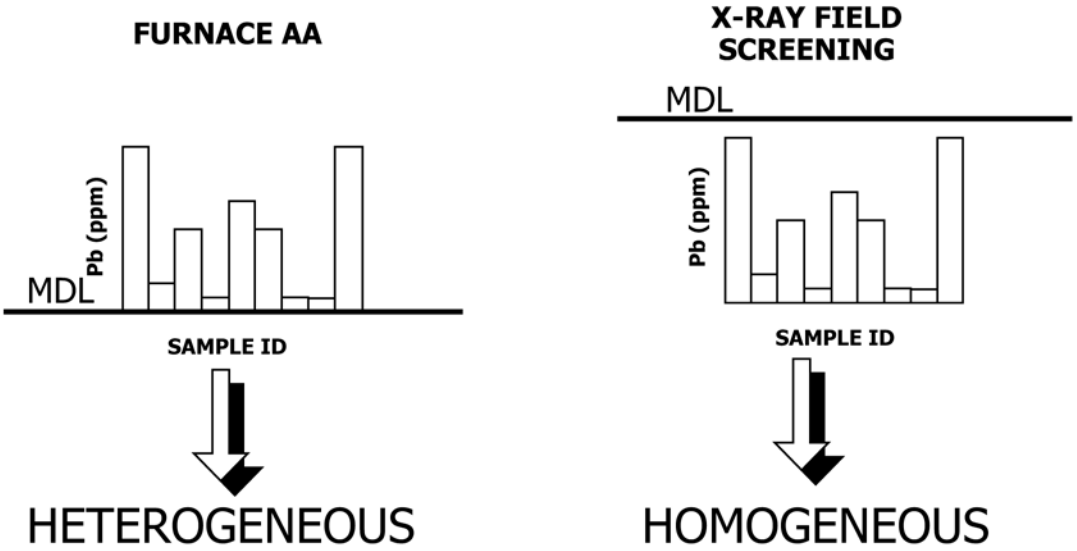


FIG. A1.3 Heterogeneity Relative to Method Detection Limits (MDLs)

collect a number of samples and compile the analytical results in a database that is used to make inferences regarding the population.

A1.3.2 Due to the different meanings assigned to the term *sample* and to minimize confusion the term *physical sample* is used throughout this discussion. Physical sample is a reference to the sample held in a sample container or that portion of the population that is subjected to in situ measurements. The term *sample size* also can have different meanings. Although use of multi-word terms can appear wordy, to avoid confusion, specific terms such as sample mass, sample volume, and number of samples are used.

A1.3.3 The accuracy of inferences made to populations are dependent on how well the physical samples represent the population characteristic of interest. The term *representativeness* usually is associated with mean concentrations. Physical samples, however, also are used to measure other statistical parameters of the population, such as variance, trends, and proportions.

A1.3.4 Sampling of a theoretically homogeneous population always results in physical samples that represent the characteristics of the population, assuming that the sampling process itself does not introduce contamination or allows for selective loss of waste constituents. The lack of variance in a homogeneous population ensures all physical samples collected from the population are identical and representative of the population.

A1.3.5 The meaning of the term *representative sample* is susceptible to misinterpretation since it connotes a single sample. The difficulty in collecting a single physical sample that represents a population increases with increasing heterogeneity. When trying to represent a heterogeneous population, it is more appropriate to collect a number of physical samples. If the physical samples are collected according to a properly designed plan, the population is better represented by the characteristics associated with the entire set of physical samples. Such a set of physical samples would be referred to as a representative set of physical samples.

A1.3.6 To properly represent a characteristic of a heterogeneous population, more than one physical sample usually is required. Samples collected from a heterogeneous population will display intersample variance. Intersample variance measured between different physical samples results from the following:

A1.3.6.1 Differences in the composition of items between sampling locations;

A1.3.6.2 Differences in how these items are distributed throughout the population; and,

A1.3.6.3 Sampling and analytical errors that ideally will be minimal so that the true intersample variance can be measured.

A1.3.7 The intersample variance may be used to make inferences about the homogeneity or heterogeneity of the population. The accuracy of these inferences will be a function of the sampling design and the quality of the sampling efforts used to collect the samples and of the analytical efforts used to generate associated data.

A1.4 *Populations and Samples:*

A1.4.1 Homogeneity and heterogeneity are population attributes estimated by the evaluation of physical samples. Representativeness of a population characteristic and intersample variance are sample attributes. Physical samples are used to measure the homogeneity and heterogeneity of a population.

NOTE A1.1—If the entire physical sample is analyzed, the heterogeneity of the physical sample is not relevant. Physical samples only are assigned attributes of heterogeneity or homogeneity when they are being subsampled since at this time the physical sample is the population whose characteristics must be represented in the subsample.

A1.4.2 Physical samples are collected from the population, evaluated, and the resulting information is employed to make inferences regarding the entire population. The value of physical samples is related directly to how accurately they represent the population characteristics of interest. The value of the inferences about a population are only as good as the associated samples. To properly represent a population characteristic, sampling location, sample mass, sample collection methods, the number of physical samples and compositing of physical samples are controlled.

A1.4.3 In a nonrandom heterogeneous population, the concentration of a target constituent (for example, arsenic) or the degree to which a property (for example, ignitability) is expressed is correlated with time, space, component, or waste source. Conversely, the constituent or property displays no correlation with time, space, component, or waste source in a random heterogeneous population.

A1.4.4 Samples collected from nonrandom heterogeneous populations, therefore, display a correlation of constituent concentrations or properties with time, space, components, or waste source and less intersample variance when samples are collected from the same stratum. Samples collected from random heterogeneous populations display a significant amount of intersample variance but no correlation of concentration or property with space, time, component, or waste source. In summary:

Homogeneous	no significant intersample variance
Random heterogeneous	significant intersample variance
Nonrandom heterogeneous	significant intersample variance and correlation of concentration/property with time, space component, or waste source

A1.4.5 Table A1.1 summarizes the attributes of physical samples and populations, as well as the inferences that can be made from variance and concentration information. Fig. A1.4 illustrates the process of using variance and concentration information to classify the type of heterogeneity.

A1.4.6 The relationship of physical samples to a population is explored in the following example. This example is designed to show the role physical samples play in the evaluation of population characteristics. In particular, this example emphasizes the impact of sample mass, particle size, and sample

TABLE A1.1 Population and Sample Attributes

Population Attribute	Sample Description	Sample Attribute	Inference
Homogeneous (theoretical homogeneity)	All samples contain only identical items.	No significant intersample variance. No correlation of concentration or properties with time, space, component, or waste source.	Samples are representative of a homogeneous population.
Practical homogeneity	All samples contain dissimilar items, but each sample contains similar proportions.	No significant intersample variance. No correlation of concentration or properties with space, time, component, or waste source.	Samples are representative of a homogeneous population.
Random heterogeneous	All samples contain dissimilar items, each sample has different proportions, but these proportions are not correlated with time, space, or components.	Significant intersample variance. No correlation of concentration or properties with space, time, component, or waste source.	Samples are representative of a random heterogeneous population.
Nonrandom heterogeneous (stratified)	All samples contain dissimilar items, each sample has different proportions and these proportions are correlated with time, space, components, or source.	Significant intersample variance. Correlation of concentration or properties with space, time, component, or waste source.	Samples are representative of a nonrandom heterogeneous population.

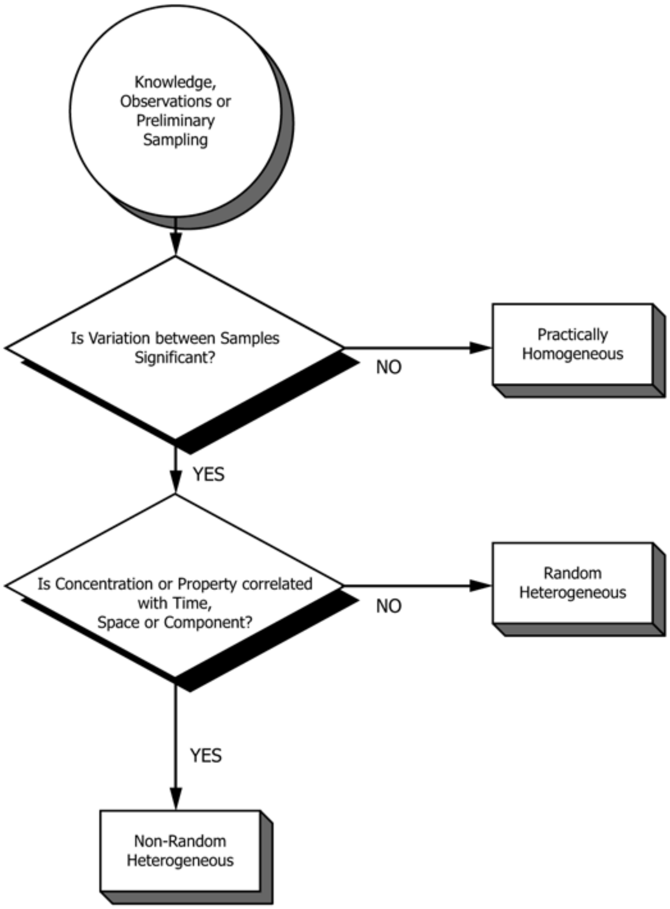


FIG. A1.4 Process for Classifying Type of Heterogeneity By Measurement or Process Knowledge

collection on sample representativeness and the resulting inferences for population characteristics.

A1.4.7 The population consists of a 2-L waste container that has 1-g nuggets of cadmium randomly distributed throughout an otherwise homogeneous and cadmium-free matrix. The cadmium-free matrix has a substantially smaller particle size than that of the cadmium nuggets. The cadmium nuggets constitute 37 % of the waste on a weight basis. The waste is composed of dissimilar particles resulting, in compositional differences and allowing distributional differences within the population. It is assumed that after collection, the entire physical sample is analyzed for cadmium.

Characteristics of interest: cadmium concentrations
Statistical parameters of interest: mean and standard deviation

A1.4.7.1 The following information pertains to Sampling Design No. 1 (Fig. A1.5).

Physical samples mass: 0.1 g
Sampling locations chosen randomly
Number of samples: 10
Sample collection device: a small spatula
Cadmium data: all 10 samples had concentrations less than 0.2 mg/kg
Average <0.2 mg/kg ± 0 mg/kg (<0.2 mg/kg = Method Detection Limit, MDL)

The lack of variance between physical samples (that is, no significant intersample variance) indicates falsely that the population is homogeneous with regards to cadmium. This is an incorrect evaluation since the physical samples are not representative of the population as a result of the sample collection method, which discriminated against the larger cadmium particles.

A1.4.7.2 The following information pertains to Sampling Design No. 2 (Fig. A1.6).

Physical samples mass: 1 g
Sampling locations chosen randomly
Number of samples: 10
Sample collection device: a spatula approximately 10 × larger than the one used in the previous example
Cadmium data: 100 %, <0.2 mg/kg, <0.2 mg/kg, <0.2 mg/kg, <0.2 mg/kg, 100 %, <0.2 mg/kg, <0.2 mg/kg, <0.2 mg/kg, <0.2 mg/kg (<0.2 mg/kg = Method Detection Limit, MDL)
Average: 20 ± 42 %

The variance between physical samples (that is, existence of significant intersample variance) indicates that the population is heterogeneous with regards to cadmium. Although more representative of the population characteristic than Sampling Design No. 1, this design also suffers from a sample collection error since the large cadmium particles were not collected unless they were aligned perfectly with the sampling device. Since only two samples had detected cadmium concentrations, there is a 25 % chance that these two samples could have occurred in the top half or the bottom half of the waste container (that is, there is a significant correlation of concentration to space). If this had occurred, the incorrect assumption may have been made that the population was nonrandomly heterogeneous (stratified) with a stratum of pure cadmium in half the container with the other half of the container consisting of cadmium-free material. These samples do not properly represent the population characteristic.

A1.4.7.3 The following information pertains to Sampling Design No. 3 (Fig. A1.7).

Physical samples mass: 30 g
Sampling locations chosen randomly
Number of samples: 10
Sample collection device: tube with a diameter that can easily accommodate a number of cadmium particles and can take a core from top to bottom
Cadmium data: 35 %, 50 %, 39 %, 24 %, 32 %, 47 %, 43 %, 27 %, 29 %, 44 %
Average: 37 ± 8.9 %

The sample mass required by this sampling design allowed for proper extraction and evaluation of the resulting physical samples yielding a database that was representative of the population (that is, there is significant intersample variance and that concentration is not correlated with space). The waste would be considered randomly heterogeneous with regards to cadmium.

A1.4.8 The previous three designs for sampling the same population showed how the perception of population heterogeneity can be affected by sampling design. The usefulness of using physical samples to make inferences regarding population heterogeneity varies according to the ability of the sampling device and the resulting sample mass to accommodate all the different-sized items of a population and the ability of all collected physical samples, as a set, to accommodate representative amounts of all constituents of the population.

A1.4.9 These previous sampling designs assumed that the entire physical sample was subjected to analysis. Practical experience indicates that most physical samples will be subjected to subsampling prior to analysis. Fig. A1.8 graphically depicts the common relationship between populations, physical

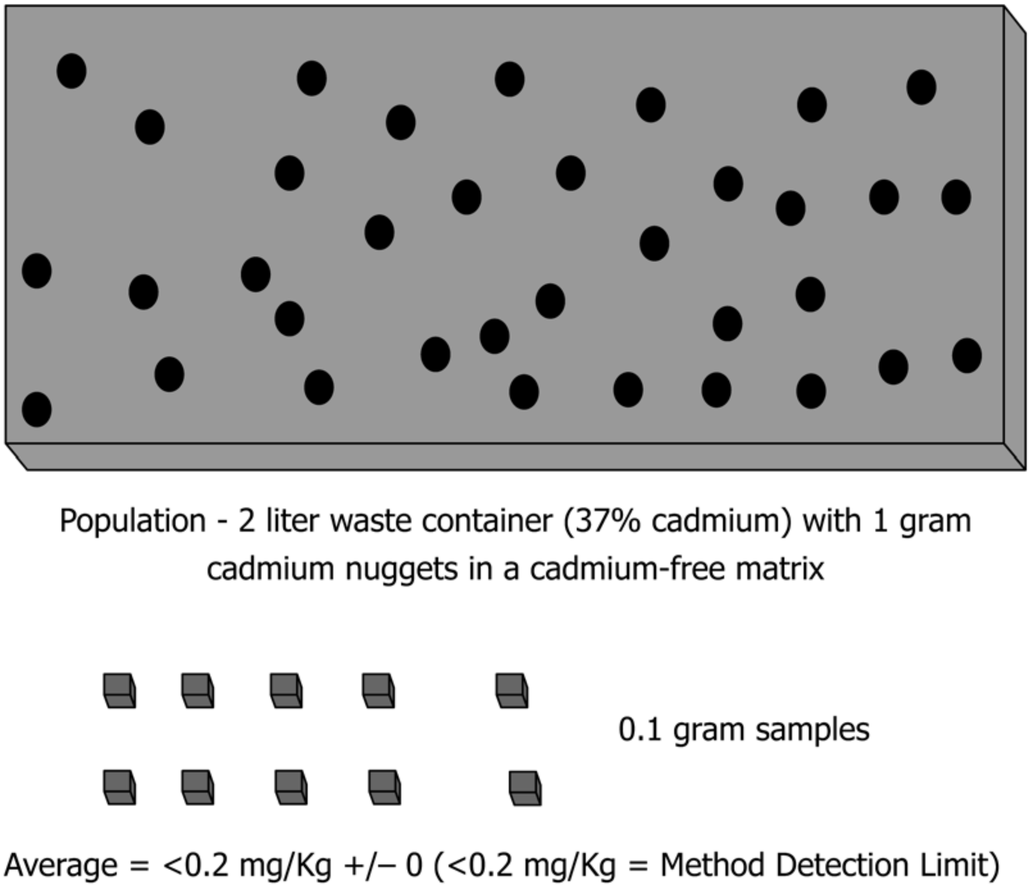


FIG. A1.5 Sampling Design No. 1

samples, subsamples, and data. If subsampling is employed, then subsamples are the windows through which the population is viewed, and the subsamples will be used to make inferences including those regarding the homogeneity, random heterogeneity, or nonrandom heterogeneity of the population. Subsampling, when required, becomes an additional critical step that must be implemented properly to ensure the accuracy of inferences.

A1.5 *Population Attributes and Sampling Design:*

A1.5.1 The relationship between physical samples and populations clearly implies that knowledge of population attributes and use of this knowledge should decrease the bias and increase the precision of sampling. Table A1.2 and Fig. A1.9 respectively tabularize and depict the relationship between critical sampling design decisions and population attributes, planning information and specifications gleaned from planning processes such as the DQO process, and, analytical requirements.

A1.5.2 In addition to budget constraints, the following information, to the extent that it is known, should be considered during sampling design:

A1.5.2.1 *Population Attributes:*

(1) Heterogeneity—Heterogeneity of the population in terms of the characteristic of interest; homogeneous, randomly heterogeneous, or nonrandomly heterogeneous (stratified).

(2) Item Size—The size of items present in the population including items that may or may not contain the characteristic of interest.

(3) Population Accessibility—The ability or inability to access all portions of the population for purposes of sampling.

A1.5.2.2 *DQOs:*

(1) Statistic—The mean, mode, variance, proportion, or other measure of a population which is of interest.

(2) Level of Confidence—The specified level of confidence that decisions will be correct. In other words, the maximum decision error rate that is acceptable to the decision maker.

(3) Boundaries—The temporal and spatial boundaries of the population that is to be studied.

A1.5.2.3 *Analytical Requirements:*

(1) Analytical Sample Volume/Mass—The sample volume/mass needed to prepare and analyze physical samples.

(2) Analyte/Media Integrity—The handling, containerization, preservation, and shipping procedures required to maintain the physical, compositional, and legal integrity of the physical samples.

A1.5.3 *Sample Mass or Volume*—The appropriate sample mass or volume will be determined by considering the size of the largest items contained within the population, the heterogeneity of the population, and the optimum sample mass/volume for preparation and analysis. Knowledge of item sizes

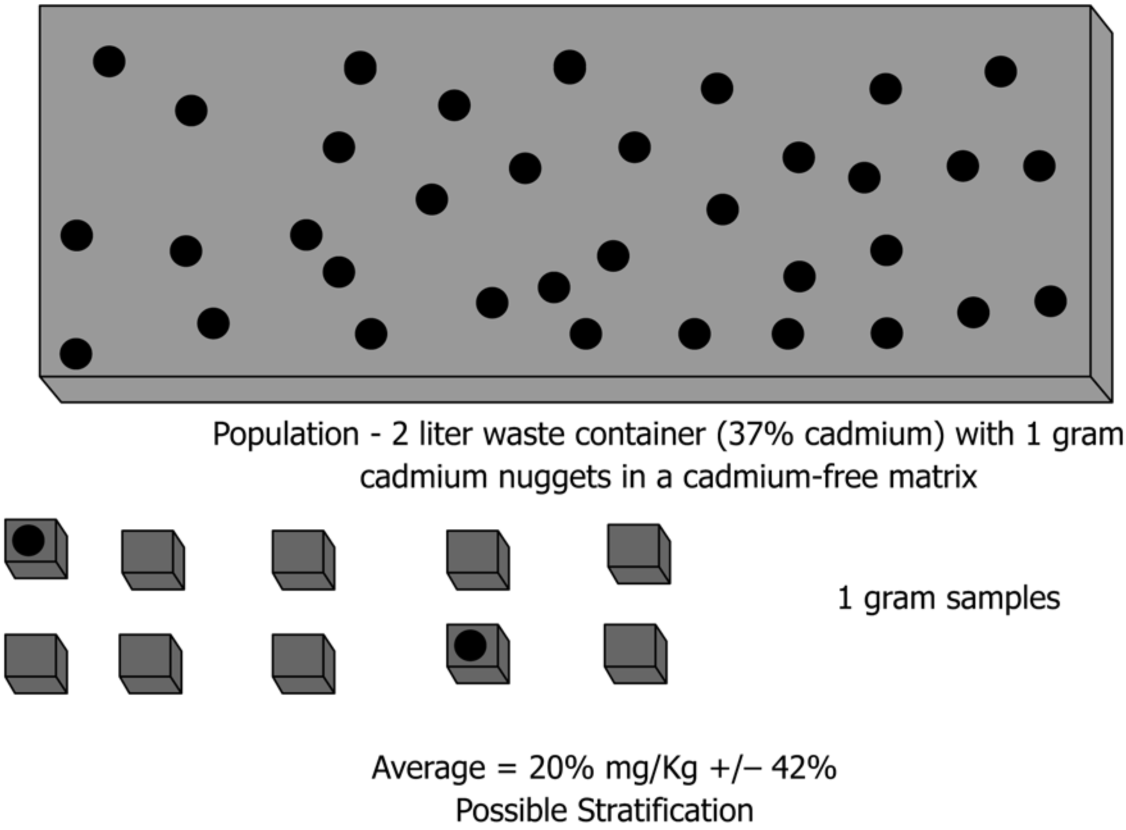


FIG. A1.6 Sampling Design No. 2

contained within a population and their content of the characteristic of interest are needed to choose the correct sample mass/volume. Bias can result if certain item sizes are discriminated against during sampling. The correct sample mass/volume will accommodate all item sizes or be chosen such that the impact of any discrimination is accounted for and understood. The variance of data caused by local heterogeneity of the population may be controlled by using a properly sized sampling device and by taking greater sample volumes or masses.

A1.5.4 *Sampling Locations*—Sampling locations are a function of the population boundaries, the accessibility of all portions of the population, and the type of heterogeneity. Other than background and other reference samples, sampling usually is restricted to those accessible areas within the population boundaries.

NOTE A1.2—Since sampling of inaccessible portions of the population is not possible, any extrapolation of sampling/analytical data to these areas must be well-documented. Extrapolation to unsampled areas is a judgment call and not a statistically valid inference. The type of heterogeneity may impact the sample locations since the existence or potential existence of strata may alter the sampling strategy for choosing sampling locations, for example, simple random versus stratified random.

A1.5.5 *Number of Samples*—The number of samples collected is determined after considering the population heterogeneity and information and specifications generated during the initial stages of the planning process, that is, the statistic of interest, the levels of uncertainty in decision-making and the population boundaries. If a population is not substantially larger than the physical sample and the distribution of the characteristic of interest is randomly heterogeneous, it may be appropriate to collect a fewer number of samples by a random or systematic sampling procedure. If a population is relatively large as compared to the physical sample and the characteristic of interest is nonrandomly distributed (stratified), a greater number of samples and a stratified sampling approach may be needed to achieve similar levels of precision and bias and the specified confidence level.

A1.5.6 *Composite Versus Discrete*—A composite sample is made by combining one or more discrete samples (physical samples) into one sample. Compositing has the potential advantage of yielding a more accurate estimate of average concentrations or average properties. Compositing, however, has the potential disadvantage of losing pertinent variance information and the possibility of diluting hot spots such that the average results fall below thresholds or limits of detection. The chosen statistical approach for data evaluation, the acceptable level of uncertainty, the type of heterogeneity, and budgets are considered when deciding between the use of composite and discrete samples.

A1.5.7 *Sampling Devices*—The choice of sampling devices is made after determining the analytical-sample requirements, the size of the largest items that must be accommodated by the sampling device, the accessibility of sampling locations, sample integrity, and reactivity of sampling-device materials.

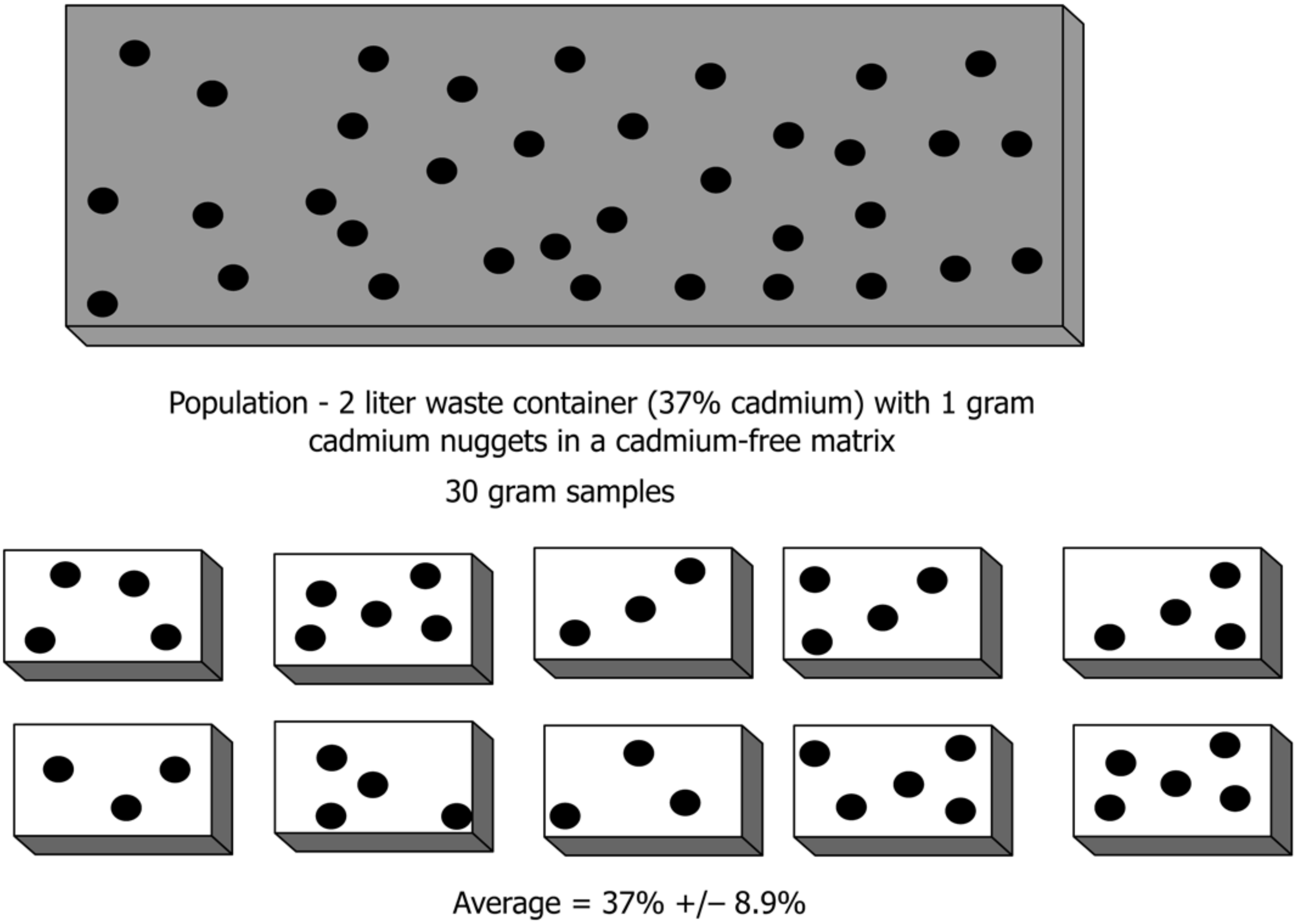


FIG. A1.7 Sampling Design No. 3

A1.5.8 Comprehensive knowledge of population attributes is infrequent and the degree of knowledge varies from population to population. However, the more thorough the planning process and the better the understanding of a population's attributes, the more likely that samples and associated data will be representative of the characteristic of interest.

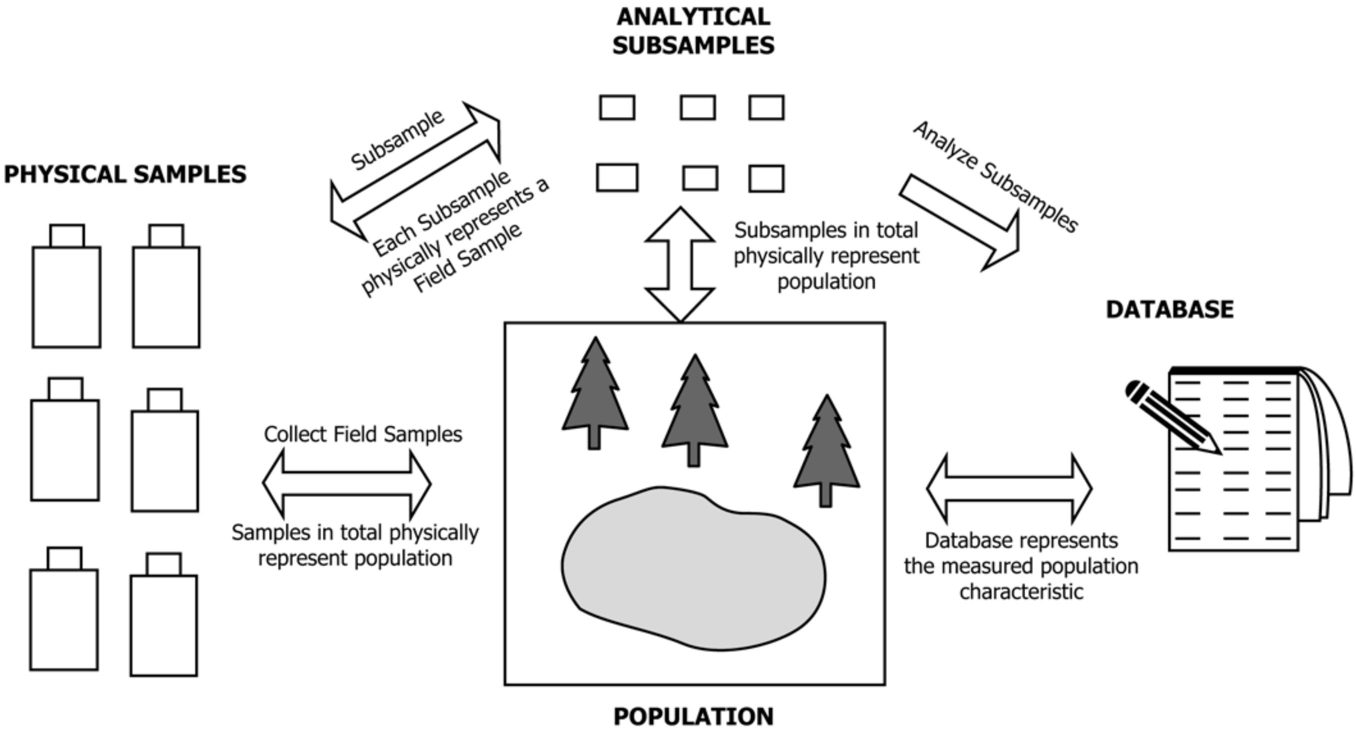
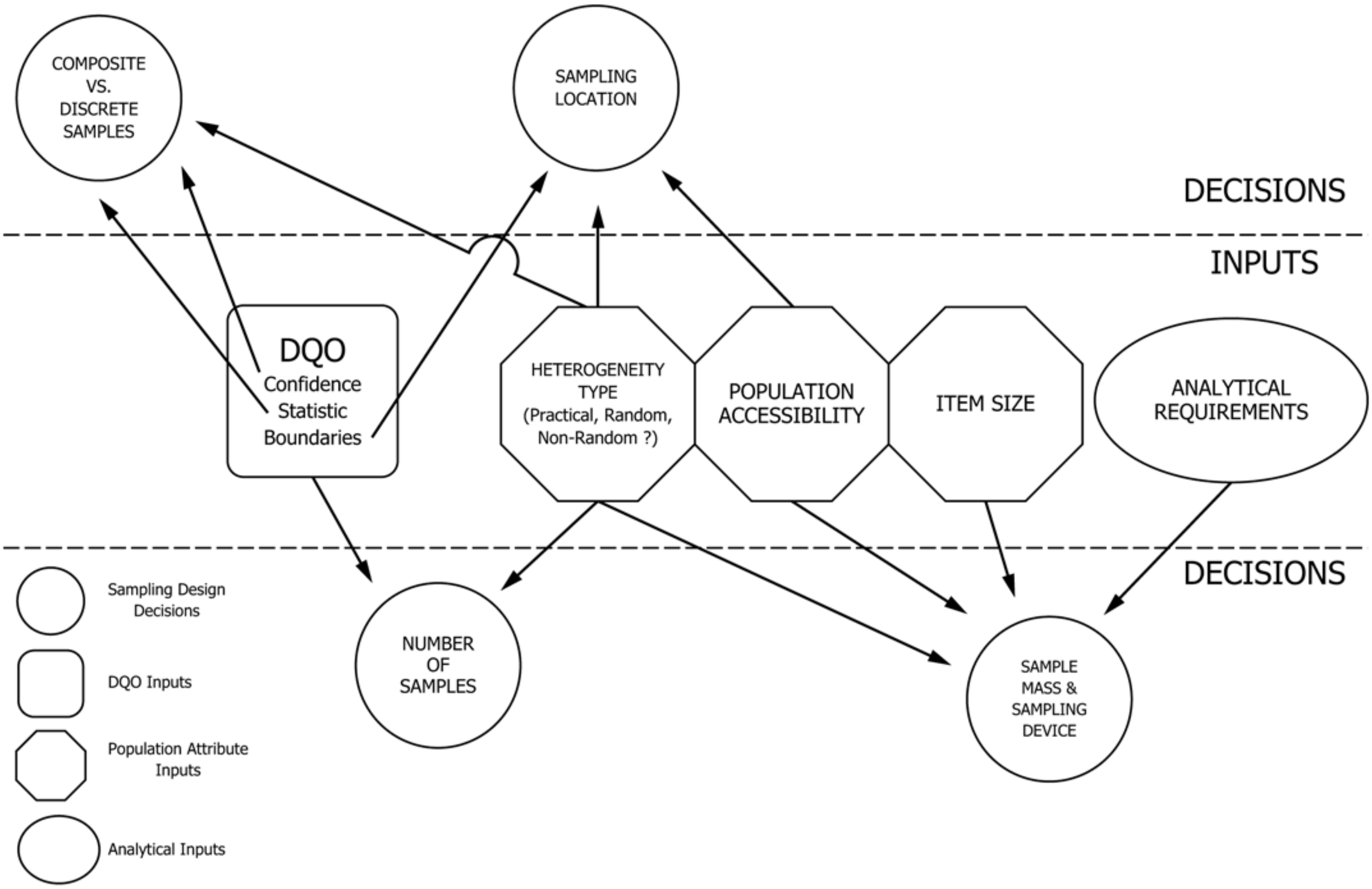


FIG. A1.8 Process of Using Physical Samples to Measure a Characteristic of the Population

TABLE A1.2 Role of Population Attributes, DQOs, and Analytical Requirements in Optimizing Sampling Designs[A]

	Inputs into Decision-Making Process						
Sampling Design Decisions	DQO Confidence Level	DQO Statistic	DQO Boundaries	Heterogeneity Type	Population Accessibility	Item Size	Analytical Requirements
Number of samples	X[B]	X	X	X			
Sampling location			X	X	X		
Sample mass/volume				X		X	X
Sampling device					X	X	X
Composite versus discrete	X	X		X			

[A] Regulatory requirements addressed during the DQO process may impact sampling design.
[B] X indicates that attribute or requirement will impact the design decision.



NOTE 1—Regulatory requirements addressed during the DQO process may impact sampling design.

FIG. A1.9 Role of Population Attributes, DQOs, and Analytical Requirements in Optimizing Sampling Designs

APPENDIX

(Nonmandatory Information)

X1. CASE STUDY FOR DESIGN OF A SAMPLING APPROACH FOR A HIGHLY STRATIFIED WASTE

X1.1 The following is a hypothetical scenario of how sample design can be optimized for highly stratified waste.

X1.1.1 A storage area contains 4000 drums of waste generated over a 15-year period. The drum contents are highly stratified and contain a myriad of wastes from process waste; destruction and construction debris such as wood, concrete; laboratory wastes including broken glassware, paper, or empty bottles. The initial stages of the planning process identified beryllium and solvents as the target characteristics and the mean and variance as the statistics of interest. In addition, groundwater modeling indicated that the storage area is the source of a plume contaminated with solvents and beryllium.

X1.2 *Sampling Design:*

X1.2.1 *What are the target characteristics?* Solvents and beryllium are the target characteristics identified during the planning process. The average and variance are the statistics of interest.

X1.2.2 *Are the target characteristics correlated with an identifiable strata or source?* The source of beryllium is traceable to one process, whose waste easily should be identifiable even when drum markings are not legible. The solvents are likewise traceable to a machine shop that disposed of its waste in easily identified drums. Testing will have to be performed to determine if there is any correlation with item size, space, time, or components in the waste.

X1.2.3 *Can any waste components or strata be eliminated from consideration during sampling?* Historical information indicated that 400 drums of construction debris were generated during construction of a new warehouse. The information indicates that the virgin nature of the materials may make these drums candidates for less intensive sampling or no sampling. Likewise, the source of beryllium contamination is a beryllium sludge that exists in drums by itself or in drums commingled with shredded packing material and laboratory wastes that were generated during physical testing of the beryllium product. Since the materials commingled with the beryllium waste are known not to be a source of contamination, the commingled material can be discriminated against during sampling, and only the beryllium sludge sampled and the volume contribution of the commingled material noted.

X1.2.4 *Are contamination levels correlated with item size?* Some of the older beryllium sludge has dried and formed a cementaceous aggregate of different item sizes. Since the sludge is known to be homogeneous within a batch, by process knowledge and preliminary sampling data, sampling can be restricted to the more easily sampled, smaller item sizes.

X1.2.5 *Is contamination innate or surface adsorbed?* The waste from the machine shop consists of varied material from fine metallic filings to large chunks of metal and out-of-specification metal product. Since the only contamination in the machine shop is solvents and cutting oils and the waste matrix is impervious, the contamination is surface adsorbed in nature. Sampling of these wastes, therefore, will consist of the sampling of fines that will be subjected to extraction, wipe sampling of the large metallic objects, and notation of the volume contributions of the different item sizes. It is essential that all assumptions (that is, any correlations) be verified at least by knowledge of the waste and preferably confirmed by exploratory sampling and analyses.

X1.3 In the preceding hypothetical case, the proposed strategy for characterizing the 4000 drums resulted in the following:

X1.3.1 The identification of two large strata that constitute the majority of the waste (that is, the beryllium sludge and the solvent and cutting oil contaminated machine shop waste),

X1.3.2 The elimination of the need to sample 10 % of the drums (that is, the construction debris) if preliminary testing verifies waste disposal information,

X1.3.3 Simplified sampling of the beryllium commingled waste by restricting sampling to the beryllium sludge and not the other commingled materials if preliminary testing verifies waste disposal information, and

X1.3.4 Simplified sampling of the cementaceous beryllium sludge by limiting sampling to the more easily sampled small items if preliminary testing verifies waste disposal information.

X1.4 Simplifying the sampling of the machine wastes, since the source of contamination is surface adsorbed and not innate to the waste materials if preliminary testing, verifies waste disposal information.

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