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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.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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

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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 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**).[2]

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

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

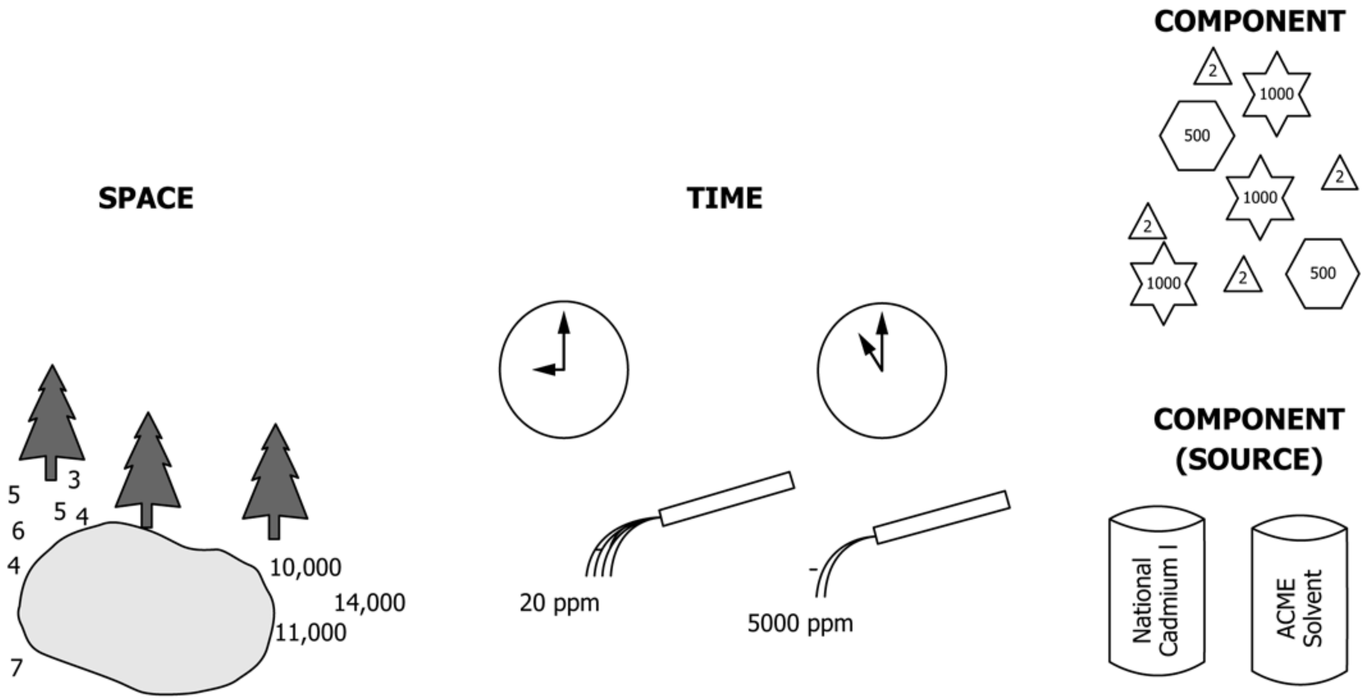

FIG. 1 Types of Stratified Heterogeneous Wastes

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.

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.

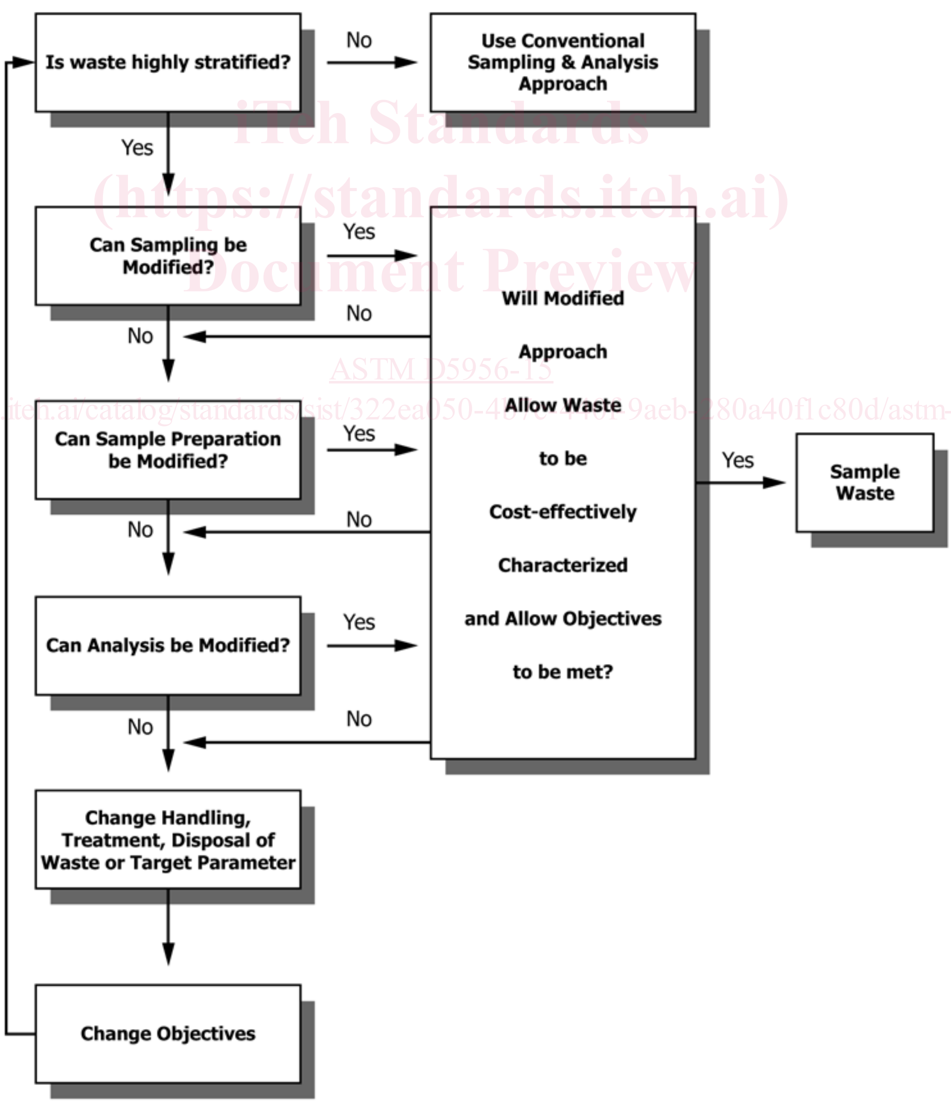

FIG. 2 Approach for the Characterization of Heterogeneous Wastes