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Standard Guide for
Evaluating Asbestos in Dust on Surfaces by Comparison Between Two Environments[1]

This standard is issued under the fixed designation D7390; 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 There are multiple purposes for determining the loading of asbestos in dust on surfaces. Each particular purpose may require unique sampling strategies, analytical methods, and procedures for data interpretation. Procedures are provided to facilitate application of available methods for determining asbestos surface loadings and/or asbestos loadings in surface dust for comparison between two environments. At present, this guide addresses one application of the ASTM surface dust methods. It is anticipated that additional areas will be added in the future. It is not intended that the discussion of one application should limit use of the methods in other areas.

1.2 *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.* For specific warning statements, see 5.7.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D5755 Test Method for Microvacuum Sampling and Indirect Analysis of Dust by Transmission Electron Microscopy for Asbestos Structure Number Surface Loading
D5756 Test Method for Microvacuum Sampling and Indirect Analysis of Dust by Transmission Electron Microscopy for Asbestos Mass Surface Loading
D6480 Test Method for Wipe Sampling of Surfaces, Indirect Preparation, and Analysis for Asbestos Structure Number Surface Loading by Transmission Electron Microscopy
D6620 Practice for Asbestos Detection Limit Based on Counts
E105 Practice for Probability Sampling of Materials
E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
E456 Terminology Relating to Quality and Statistics
E2356 Practice for Comprehensive Building Asbestos Surveys

2.2 *Other Document:*

Environmental Protection Agency, U.S. (EPA), (Pink Book) Asbestos in Buildings: Simplified Sampling Scheme for Surfacing Materials, EPA 560/5/85/030A, U.S. Environmental Protection Agency, Washington, DC, 1985[3]

3. Terminology

3.1 *Definitions*—Unless otherwise noted all statistical terms are as defined in Terminology E456.

3.1.1 *activity generated aerosol*—a dispersion of particles in air that have become airborne due to physical disturbances such as human activity, sweeping, airflow, etc.

3.1.2 *background samples*—samples taken from surfaces that are considered to have concentrations of asbestos in surface dust that are representative of conditions that exist in an environment that is affected by only prevailing conditions and has not experienced events, disturbances or activities unusual for the environment.

3.1.3 *control*—an area that is used as the basis for a comparison. This could be an area where the dust has been previously characterized, an area thought to be suitable for occupancy, an area that has not experienced a disturbance of asbestos-containing materials, or that is for some other reason deemed to be suitable as the basis for a comparison.

3.1.4 *control samples*—samples collected for comparison to the study samples. These differ from background samples in that they are collected: either: in an area where the dust has been previously characterized, or in an area that has not experienced a disturbance of asbestos-containing materials, or

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

[3] Available from United States Environmental Protection Agency (EPA), Ariel Rios Bldg., 1200 Pennsylvania Ave., NW, Washington, DC 20460, http://www.epa.gov.

in an area that is for some other reason deemed to be suitable as the basis for comparison.

3.1.5 *dust*—any material composed of particles in a size range of <1 mm.

3.1.6 *environment*—well defined three-dimensional area and everything that is in it.

3.1.7 *homogeneous samples*—group of samples that are collected from surfaces that are visually similar in texture, dust loading and environment.

3.1.8 *laboratory blank*—a cassette or wipe taken from laboratory stock that are not affected by field activities.

3.1.9 *loading*—quantity of asbestos in the dust found on a surface as measured by the ASTM standard methods for evaluating asbestos in dust on surfaces.

3.1.10 *open field blank*—cassette or wipe opened in the field as if for sample collection and then immediately closed. This blank is analyzed in the same manner as a regular sample.

3.1.11 *power*—power of the test is the probability, expressed as a decimal fraction, that a specified difference between asbestos surface loadings in two environments will be detected by the test.

3.1.12 *replicates*—samples collected from an area that is visually identified as homogeneous.

3.1.13 *sampling set*—samples collected on the same day on surfaces in an area for the purpose of characterizing the asbestos loading in the dust of the samples surfaces in that area.

3.1.14 *sealed field blank*—cassette or wipe taken to the field but remaining closed at all times.

3.1.15 *study samples*—samples collected in an area believed to have experienced events, disturbances or activities affecting asbestos-containing materials. The area in which these samples are taken is called the study area. Study samples are compared to background samples or control samples.

4. Summary of Guide

4.1 The guidance contained in this document was developed for applications of Test Methods D5755, D5756, and D6480. The application addressed in this document is sampling to test for differences in surface loading in two or more environments including comparison to environments that may be considered to be "background."

4.2 Factors affecting the selection of sampling sites and types of samples to be collected are described in Appendix X1. These factors include:

4.2.1 Uniformity and distribution of dust within a building,

4.2.2 The nature of dust found within buildings,

4.2.3 The nature of the surface from which samples are to be collected,

4.2.4 Past disturbances of asbestos-containing materials,

4.2.5 Environmental conditions,

4.2.6 Ventilation,

4.2.7 Building history,

4.2.8 Occupation and activity of occupants, and

4.2.9 Outdoor sampling.

4.3 This guide describes statistical procedures to be used for:

4.3.1 Defining sampling needs including the size, number and location of samples required to address a particular application; and

4.3.2 Interpreting analytical results—estimating loadings or loadings from single or multiple-sample results, establishing confidence intervals for such estimates, and comparing between such estimates.

5. Significance and Use

5.1 This guide describes factors to be considered by an investigator designing a sampling program to compare the asbestos dust loadings in two environments and presents statistical methods for making the comparison. Each user is responsible for the design of an investigation and the interpretation of data collected when using dust data.

5.2 This guide does not deal with situations where dusts of different compositions or from different surfaces are to be evaluated.

5.3 This guide describes methods for interpreting the results of sampling and analysis performed in accordance with Test Methods D5755, D5756, and D6480. It may be appropriate to use the procedures in this Guide with other dust collection and analysis methods, but it is the responsibility of the user to make this determination.

5.4 The methods described in this guide are not intended to be used alone. They are intended to be used along with various evaluation methods that may include consideration of building use, activities within the building, air sampling, asbestos surveys (refer to Practice E2356), evaluation of building history and study of building ventilation systems.

5.5 This guide describes methods for comparing environments and does not draw any conclusions relating asbestos surface loadings to the potential safety or habitability of buildings.

5.6 This guide does not address risk assessments or the use of dust sampling in risk assessment. Health based risk assessments are beyond the scope of this guide.

5.7 **Warning—**Asbestos fibers are acknowledged carcinogens. Breathing asbestos fibers can result in disease of the lungs including asbestosis, lung cancer, and mesothelioma. Precautions should be taken to avoid creating and breathing airborne asbestos particles when sampling and analyzing materials suspected of containing asbestos. Regulatory requirements addressing asbestos are defined by USEPA[4,5] and OSHA[6].

6. Comparison Between Environments

6.1 One use of dust sampling is to compare the asbestos dust loadings on surfaces in two environments. This Guide describes two ways in which such a comparison might be made.

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[4] USEPA, 40 CFR Part 61, Subpart M.

[5] USEPA, 40 CFR Part 763, Subpart E.

[6] OSHA, 29 CFR Parts 1910, 1915, and 1926.

6.1.1 *Comparison to Background Samples*—If one environment is considered to represent conditions that are typical of a building this could be used as the source of background samples against which study samples from areas in questions could be compared. Areas may be in question due to disturbance of an asbestos-containing material, damage to the building materials, change in occupancy or any other occurrence that could change the asbestos loading in dust.

6.1.2 *Comparison to Control*—One environment may be taken as a "Control" against which to compare study samples from other environments. For example, samples collected in a building to which cleaned items are to be delivered might be used as control samples. Samples collected on cleaned items would then be compared to these Control samples to determine if the cleaned items could be released for delivery.

6.2 *Sample Collection Requirements:*

6.2.1 *Homogeneous Dust*—A visual determination should be made about the homogeneity of the dust and sample site to be sampled. Samples in each environment should be collected from homogeneous locations. A location is considered to be homogeneous if:

6.2.1.1 The sample sites have visually similar depositions of dust on their surfaces.

6.2.1.2 The surfaces to be sampled have the same type of surface texture based upon a visual determination.

6.2.1.3 The efficiency of dust collection on a given surface is likely to be different for wipe and microvacuum methods (see Crankshaw et al, Ref (**6**)).[7] As such, the same sample collection method should be used for samples that are to be compared.

NOTE 1—If the laboratory reports comparing two areas indicate that the analytical sensitivities, particle sizes or structure types for any sample or a group of samples differ greatly from the balance of the samples, then this could indicate that the dust in the areas selected was not homogeneous. In these instances other methods of comparison may be considered.

6.3 *Selection of Sampling Locations:*

6.3.1 *Random Sampling*—Samples should be collected from locations that are selected at random from all available locations in the environment to be tested. Genuinely random procedure such as the grid and random number procedure set forth in the USEPA Pink Book, coin tosses, or a random number table are acceptable for this purpose.

6.3.1.1 In situations in which accessibility for sampling is limited the general location of samples should be determined by random means and the specific sample site determined by accessibility within the randomly selected area. The dust at the specific sampling site should be visually evaluated to determine if it is representative of conditions prevailing in the environment.

6.4 A sufficient number of samples need to be collected to be able to discern differences that may exist between the environments. The Annex describes methods for determining the number of samples necessary to accomplish this goal. The number of samples required depends, in part, upon the sensitivity of the analysis. As this sensitivity will not be known until the analysis is complete it is prudent to collect additional samples in case the sensitivity of actual samples does not match preliminary estimates used in planning the sampling.

6.5 *Sampling and Analytical Requirements:*

6.5.1 Collect and analyze samples as described in Test Methods D5755, D5756, or D6480.

6.6 *Quality Control Requirements:*

6.6.1 *Blanks*—The following blanks should be collected as part of the sampling:

6.6.1.1 A sealed field blank per lot of cassettes or wipes.

6.6.1.2 One open field blank for each ten samples (a minimum of one open field blank per environment sampled).

6.6.1.3 Blanks should be sent to the laboratory for analysis in the same manner as a regular sample. Blanks need not be analyzed if no asbestos is found in the study samples. If asbestos is found in the study samples the "Open Field Blanks" should be analyzed. If asbestos is found on the "Open Field Blanks," then the "Sealed Field Blanks" should be analyzed. If no asbestos is found on the "Open Field Blank" there is no need to analyze the sealed blanks. If any blank is found to contain more than the limit set forth in the section on blanks in the appropriate method then the sampling may be considered to be suspect.

6.7 *Data Interpretation:*

6.7.1 For each sample the number of asbestos structures counted, analytical sensitivity of the analysis, and asbestos loading should be extracted from the laboratory reports. The upper and lower 95 % confidence limits should be calculated using the procedures in Annex A1. Refer to Note 1 in 6.2.1.3 regarding analytical sensitivity.

6.7.1.1 For each group of samples for an environment the procedures of Annex A1 should be applied to the data in 6.7.1 to calculate the total asbestos structures counted, sum of sensitivity weights, and estimate of asbestos loading for the environment along with upper and lower 95 % confidence limits on this estimate.

6.7.2 There are two ways to make a decision about whether there is a difference between two areas. The first of these is to simply compare the confidence limits of the two sets of samples. If this comparison shows that the two sets of samples are clearly the same, or are clearly different then no further comparison is required. However, if there is a question about the comparison of the confidence limits or this comparison is inconclusive a Z-test may clarify the issue.

6.7.2.1 If the confidence limits of the sample sets from two homogeneous areas overlap then the two areas can be considered to have the same asbestos loading in the dust on the sampled surfaces. If the confidence limits do not overlap then the asbestos loadings are different. Confidence limits are considered to be overlapped if the upper confidence limit of group of samples with the lower estimated mean exceeds the lower confidence limit of the group of samples with the higher estimated mean. This simple test may be augmented with other statistical tests to confirm the conclusion. This is particularly appropriate if the overlap or separation of the confidence intervals is small. Refer to Annex A1 for more information on the use of confidence limit comparison.

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

6.7.2.2 Another way of making a comparison is with the Z-test. Annex A1 describes a statistical test using a normal distribution approximation and a Z-test.

6.7.2.3 If the statistical tests in 6.7.2.1 and 6.7.2.2 give conflicting results then it is recommended that additional samples be collected to clarify the situation.

6.7.3 Consideration of the mineral form of the asbestos found during analysis of settled dust samples may help with interpretation of the data. If the mineral form of the asbestos in the two sets of samples (study samples and control or background samples) is different, the sites cannot be considered equivalent in terms of dust loadings and additional investigation may be necessary.

NOTE 2—If the size or type of asbestos structures differs between the study samples and control or background samples this also may indicate a difference in the dust loadings at each site. For example, if one set of samples consists of small fibers and the other set has large matrices, then these areas would appear to be different. As such, additional investigation may be necessary in such an instance, even if statistical analysis of the number or mass of particles finds no difference between the sites.

6.8 *Reporting:*

6.8.1 The report should contain sufficient information to allow the reader to locate the sampling sites, and repeat the sampling.

6.8.2 The complete data set should be reported, including results of blanks and background samples.

6.8.2.1 For each sample the number of asbestos structures, analytical sensitivity, asbestos loading and upper and lower 95 % confidence limits on the asbestos loading should be tabulated.

6.8.2.2 For each group of samples for a homogeneous environment the total asbestos structures counted, sum of sensitivity weights, and estimate of asbestos loading for the environment along with upper and lower 95 % confidence limits on this estimate should be reported.

6.8.2.3 The type of statistical comparisons and results of these comparisons should be given.

6.8.3 Laboratory reports should be included as an appendix to the report.

6.9 *Example 1*—The following example illustrates application of the procedures described in this guide.

6.9.1 *Situation*—An uncarpeted 20 by 20-ft storage room that has a visible layer of dust which is suspected to have come from known asbestos-containing material in the room. This area is designated as the study area.

6.9.2 *Choice of Analytical Method*—Any of the ASTM asbestos dust sampling methods could be used for this example. For the sake of illustration it is assumed that the investigator chose to use structure number loading from microvacuum collection (Test Method D5755) due to familiarity with this method.

6.9.3 In this example a background area in the same facility was chosen that matched the study area closely in its configuration, construction, use, and occupancy. This included type of surface area. The chosen area was in the same portion of the facility as the study area so it shared a common history, but was remote enough that it would not have been affected by a disturbance in the study area. Generally a study area will be selected that is considered to be acceptable for occupancy.

6.9.4 *Determination of Sample Number*—The table in A1.8.2 was used to determine the number of samples to be collected in each environment. The surfaces were relatively clean so it was assumed that the analytical sensitivity of the analysis would be no greater than 2000 s/cm^2. It was hypothesized that the loading in the study area would be about 5000 and in the background area would be around 1000 s/cm^2. The same number of samples will be collected in each area. For these conditions the table indicates that 5 samples will be needed in each area.

6.9.5 *Selection of Sampling Locations*—Both the study and background area contained bookshelves. There was visible dust on the shelves in the study area that was thought to have come from the disturbance of ACM. The book shelves in both locations were constructed of painted wood and as such are expected to have similar sample collection characteristics. The bookshelves were selected as the sample location.

6.9.5.1 Each individual shelf was given an identification number. Five shelves in each location were selected by use of a random number table. Samples were collected prior to routine cleaning of the study area.

6.9.6 *Quality Control*—In this example a sealed field blank was selected for the building, one field blank was taken for the study area, and one field blank was taken for the background area.

6.9.7 *Interpretation of Analytical Data*—Tables 1-3 give

TABLE 1 Example 1—Hypothetical Dust Sample Results

Study Area						Background Area					
Number of Structures	Analytical Sensitivity (s/cm^2)	Sensitivity Weights	Result (s/cm^2)	95 % LCL (s/cm^2)	95 % UCL (s/cm^2)	Number of Structures	Analytical Sensitivity (s/cm^2)	Sensitivity Weights	Result (s/cm^2)	95 % LCL (s/cm^2)	95 % UCL (s/cm^2)
6	205.1	0.0049	1231	452	2679	4	205.1	0.0049	820	224	2101
4	205.1	0.0049	820	224	2101	5	205.1	0.0049	1026	333	2393
7	205.1	0.0049	1436	577	2958	6	205.1	0.0049	1231	452	2679
2	205.1	0.0049	410	50	1482	4	205.1	0.0049	820	224	2101
3	205.1	0.0049	615	127	1798	6	205.1	0.0049	1231	452	2679

where:
Number of Structures = The number of structures counted as contained in the report from the analysis.
Analytical Sensitivity = The concentration represented by a single count as contained in the report from the analysis.
Sensitivity Weight = The reciprocal of the analytical sensitivity (1/analytical sensitivity).
Result = The “analytical sensitivity” multiplied by the “number of structures.” This should equal the result reported by the analytical method.
95 % LCL = The lower 95 % confidence limit as calculated using the formulas in the Annex.
95 % UCL = The upper 95 % confidence limit as calculated using the formulas in the Annex.

TABLE 2 Hypothetical Laboratory Parameters

Effective filter area (EFA)	923 mm^2
Number of grid openings examined (GO)	10
Average grid opening area (GOA)	0.009 mm^2
Sample area (SPL)	100 cm^2
Total Volume	100 mL
Volume filtered (V)	50 mL
Calculated Analytical Sensitivity	205.1 s/cm^2

TABLE 3 Example 1—Comparison of Spaces—Combine Measurements in a Weighted Average

Study Area						Background Area					
Total Structures	Weighted Analytical Sensitivity (s/cm^2)	Sum of Sensitivity Weights	Estimate (s/cm^2)	95 % LCL (s/cm^2)	95 % UCL (s/cm^2)	Total Structures	Weighted Analytical Sensitivity (s/cm^2)	Sum of Sensitivity Weights	Estimate (s/cm^2)	95 % LCL (s/cm^2)	95 % UCL (s/cm^2)
22	41.0	0.024	902	566	1366	25	41.0	0.024	1026	664	1514

data from a hypothetical laboratory report and the calculations of the upper and lower 95 % confidence limits as described in Annex A1.

6.9.7.1 In Table 3 the measurements are combined into a weighted average as described in Annex A1. As described in 6.7.2.1 the confidence limits of the study area are compared to the confidence limits for the background area. The confidence limit of the samples for the study area and the background area overlap indicating, as described in 6.7.2.1, that there is no statistical difference between the areas.

6.9.7.2 Inspection of the data in Table 3 finds that there is substantial overlap between the confidence limits for the study area and background area. It is decided that no further statistical testing in necessary.

(1) Example 1 is based on the hypothetical laboratory parameters (see Table 2) as would be found in reports from Test Methods D5755, D5756, and D6480. These parameters are typical for a nominal analytical sensitivity equal to 200 s/cm^2.

(2) To compare these two environments the sensitivity weights of the individual measurements are added together and a "Weighted Analytical Sensitivity" is calculated by taking the reciprocal of the "Sum of Sensitivity Weights." The "Estimate" of the concentration in each space is calculated by multiplying the "Weighted Analytical Sensitivity" by the "Total Structures" counted in the space. The 95 % upper and lower confidence limits for this estimate are calculated in the same manner as was used for the individual measurements.

NOTE—Refer to Practice D6620 for information on dealing with situations where there are zero structure counts.

(3) As can be seen by inspection of Table 3 the confidence limits for the study area and the background area overlap. As such there is not a statistically significant difference between the asbestos loadings in the two locations.

6.10 *Example 2*—Table 4 presents hypothetical results for the same situation described in Example 1 but where there was a need to perform serial dilutions during the analysis resulting in higher value for the analytical sensitivity for two of the samples from the study area. This affects the spread of the confidence limits resulting in broader confidence limits for the study area. As with example 1 the calculation procedures from Annex A1 have been applied. The laboratory parameters for this set of evaluations are given in Table 5.

6.10.1 Comparison of the 95 % confidence limits in Table 6 finds that there is an overlap of the confidence intervals. The simple confidence limit test of 6.7.2 thus indicates that there is no statistical difference between the two environments. This is despite the fact that the estimated asbestos loadings in the two

TABLE 4 Example 2—Hypothetical Dust Sample Results

Study Area						Background Area					
Number of Structures	Analytical Sensitivity (s/cm^2)	Sensitivity Weights	Result (s/cm^2)	95 % LCL (s/cm^2)	95 % UCL (s/cm^2)	Number of Structures	Analytical Sensitivity (s/cm^2)	Sensitivity Weights	Result (s/cm^2)	95 % LCL (s/cm^2)	95 % UCL (s/cm^2)
2	205.1	0.0049	410	50	1482	15	205.1	0.0049	3077	1722	5074
6	205.1	0.0049	1231	452	2679	19	205.1	0.0049	3897	2346	6086
15	205.1	0.0049	3077	1722	5074	2	205.1	0.0049	410	50	1482
10	10 255.6	0.0001	102 556	49 179	188 603	10	205.1	0.0049	2051	984	3772
19	10 255.6	0.0001	194 856	117 316	304 291	6	205.1	0.0049	1231	452	2679

where:
Number of Structures = The number of structures counted as contained in the report from the analysis.
Analytical Sensitivity = The concentration represented by a single count as contained in the report from the analysis.
Sensitivity Weight = The reciprocal of the analytical sensitivity (1/analytical sensitivity).
Result = The "analytical sensitivity" multiplied by the "number of structures." This should equal the result reported by the analytical method.
95 % LCL = The lower 95 % confidence limit as calculated using the formulas in the Annex.
95 % UCL = The upper 95 % confidence limit as calculated using the formulas in the Annex.

TABLE 5 Hypothetical Laboratory Parameters

Laboratory Parameters for 0.5 of Total Volume		Laboratory Parameter for Dilution to 0.01 of Total Volume	
Effective filter area (EFA)	923 mm^2	Effective filter area (EFA)	923 mm^2
Number of grid openings examined (GO)	10	Number of grid openings examined (GO)	10
Average grid opening area (GOA)	0.009 mm^2	Average grid opening area (GOA)	0.009 mm^2
Sample area (SPL)	100 cm^2	Sample area (SPL)	100 cm^2
Total Volume	100 mL	Total Volume	100 mL
Volume filtered (V)	50 mL	Volume filtered (V)	1 mL
Calculated Analytical Sensitivity	205.1 s/cm^2	Calculated Analytical Sensitivity	10 255.6 s/cm^2

TABLE 6 Example 2—Comparison of Spaces

Study Area						Background Area					
Total Structures	Weighted Analytical Sensitivity (s/cm^2)	Sum of Sensitivity Weights	Estimate (s/cm^2)	95 % LCL (s/cm^2)	95 % UCL (s/cm^2)	Total Structures	Weighted Analytical Sensitivity (s/cm^2)	Sum of Sensitivity Weights	Estimate (s/cm^2)	95 % LCL (s/cm^2)	95 % UCL (s/cm^2)
52	67.5	0.015	3508	2620	4601	52	41.0	0.024	2133	1593	2797

TABLE 7 Example 2—Z-Test

Note 1—p-value ≤ 0.05 then the two populations are different.

Z	p-value	Statistical Difference
2.50	0.01	Yes

environments appear substantially different. The 3508 s/cm^2 in the Study Area appears higher than the 2133 s/cm^2 in the Background Area. Closer inspection of the data in Table 6 discovers that the overlap between the 95 % confidence limits is small. At 2796 s/cm^2 the 95 % UCL for the Background Area overlaps the 2620 s/cm^2 for the 95 % LCL for the Study Area by only 157 s/cm^2. It is decided that additional statistical testing using the Z-test is appropriate.

6.10.2 Application of the Z-test procedure described in A1.4.3 results in a Z of 2.5 and a p-value of <0.012 which indicates that there is a significant difference between the environments.

6.10.2.1 The p-value for the Z-statistic should be reported. The convention is to conclude that the levels in the two areas being compared are different if the p-value is 0.05 or less. The p-value is the probability of a Type I error (false positive outcome) and should be judged accordingly for decision-making based on the consequences of a Type I error, as interpreted by the individual conducting the test.

6.10.3 The conflict between the results of the two tests likely arises from the fact that the actual analytical sensitivities for samples from the study area exceed the 2,000 estimated when a determination was made about the number of samples required. Based on these results it is recommended that additional samples be collected to resolve the conflict. The number of additional samples can be calculated by using the equation in A1.8.1 of Annex A1.

6.10.3.1 The additional number of samples should be determined using the procedures described in A1.8 of the Annex using sensitivities that are equal to the average of the observed sensitivities in the initial sampling.

(1) Example 2 is based on the hypothetical laboratory parameters (see Table 5) as would be found in reports from Test Methods D5755, D5756, and D6480.

(2) To compare these two environments the sensitivity weights of the individual measurements are added together and a "Weighted Analytical Sensitivity " is calculated by taking the reciprocal of the "Sum of Sensitivity Weights." The "Estimate" of the concentration in each space is calculated by multiplying the "Weighted Analytical Sensitivity" by the "Total Structures" counted in the space. The 95 % upper and lower confidence limits for this estimate are calculated in the same manner as was used for the individual measurements. The results of these calculations are shown in Table 6.

(3) As can be seen by inspection of Table 6 the 95 % upper confidence limit of the background area (2797) is higher than the 95 % lower confidence limit of the study area (2620) indicating that there is not a statistically significant difference between the asbestos loadings in the two locations. However, the overlap is small.

(4) The Z-test calculations were performed as described in the Annex with the results given in Table 7.

7. Keywords

7.1 asbestos; indirect; mass; microvacuuming; settled dust; surface; TEM; wipe

ANNEX

(Mandatory Information)

A1. STATISTICAL METHODS FOR SUMMARIZING MEASUREMENTS OF ASBESTOS LOADINGS ON SURFACES

A1.1 *Introduction*:

A1.1.1 This Annex describes statistical methods for estimating asbestos surface loadings from data developed using Test Methods D5755, D5756, and D6480, and the range of statistical uncertainty associated with the estimates. Although asbestos surface loading estimates may have a variety of risk management applications, this Annex addresses only one specific application, the comparison of asbestos surface loadings between two environments.

A1.1.2 The statistical characteristics of surface loading measurements are based on the Poisson distribution. The Poisson distribution is a reasonable probability model for structure counts, which are the data underlying surface loading measurements.

A1.1.3 If structures tend to cluster, the Poisson distribution may understate the statistical variability for an asbestos surface loading estimate. As an alternative, a generalization of the Poisson distribution is the compound Gamma-Poisson distribution, more commonly known as the Negative Binomial distribution. The Negative Binomial distribution has two parameters, one more than the Poisson distribution, which accommodates larger variability of structure count than could be achieved with the Poisson distribution. However, usually there are insufficient data available for estimating the additional parameter reliably. Therefore, this Annex describes application only of the Poisson distribution, which is viewed as an acceptable approximate model for analyzing asbestos surface loading data.

A1.2 *Asbestos Surface Loading Derived from One Sample Collected by Test Method D5755, D5756, or D6480*:

A1.2.1 *Asbestos Surface Loading Estimate*—Dust is collected from a surface using a microvac (Test Methods D5755 and D5756), or a wipe (see Test Method D6480). Sample preparation involves various steps including suspension of particles in liquid and filtration. Structures are counted by TEM.

A1.2.1.1 *Sensitivity*—The initial liquid volume and the volume deposited on the filter affect the sensitivity of the measurement. Sensitivity is calculated as follows:

$$S = \left[EFA/\left(GO \cdot GOA\right)\right] \cdot \left(100/V\right)/SPL \qquad \text{(A1.1)}$$

where:

S = sensitivity,
EFA = effective filter area for the secondary filter (mm^2),
GO = number of grid openings counted,
GOA = average grid opening area (mm^2),
V = volume of sample filtered representing the actual volume taken from the original 100-mL suspension (mL), and
SPL = area of the surface vacuumed or wiped.

A1.2.1.2 It follows that the asbestos surface loading estimate reported as STR/cm^2, is:

$$STR/\text{cm}^2 = \#STR \cdot S \qquad \text{(A1.2)}$$

where:

$\#STR$ = number of asbestos structures counted in the sample.

A1.2.2 A measurement is characterized by its sensitivity (S) and the number of structures counted (#STR). The structure loading is S·#STR. For mass, the mass of each structure and an average mass per structure for the measurement are required. If W represents the average mass of the #STR structures that were counted, the mass measurement is S·#STR·W. The confidence limits for mass would be calculated as the confidence limits for the count, #STR, multiplied by S·W. (Note that for structure loading, the confidence limits are the limits for the count, #STR, multiplied by sensitivity, S.)

A1.2.3 *Confidence Limits for Asbestos Surface Loading Derived from One Sample:*

A1.2.3.1 Upper and lower confidence limits are determined for the structure count from the Poisson distribution. These limits are multiplied by the sensitivity of the measurement to obtain upper and lower confidence limits for the asbestos structure loading. A table containing upper and lower 95 % confidence limits for the Poisson distribution is Attachment 1 to this Annex. Upper and lower confidence limits for the Poisson distribution corresponding to other confidence levels (for example, 90 %, 99 %, and generally (1-α)·100 %) may be determined from the Chi Square distribution (either tables in a statistical textbook or a probability calculator such as found in most spreadsheet programs such as Microsoft's Excel) as follows.

A1.2.3.2 If the structure count, Y, is greater than zero:

(1) The upper (1-α)·100 % confidence limit for the mean structure count is the (1-α/2) percentile of the Chi Square distribution with degrees of freedom (df) equal to 2·(Y+1), divided by 2 {i.e., $X_{(1-\alpha/2)}/2$ where $X_{(1-\alpha/2)}$ is the indicated percentile from the Chi Square distribution with 2·(Y+1) df}.

(2) The lower (1-α)·100 % confidence limit for the mean structure count is the (α/2) percentile of the Chi Square distribution with degrees of freedom (df) equal to 2·Y, divided by 2 {i.e., $X_{(\alpha/2)}/2$ where $X_{(\alpha/2)}$ is the indicated percentile from the Chi Square distribution with 2·Y df}.

A1.2.3.3 If the structure count, Y, is zero:

(1) The lower confidence limit of the mean structure count is zero.

(2) The upper confidence limit for the mean structure count is the (1-α) percentile of the Chi Square distribution with degrees of freedom (df) equal to 2·(Y+1), divided by 2 {i.e., $X_{(1-\alpha)}/2$ where $X_{(1-\alpha)}$ is the indicated percentile from the Chi Square distribution with 2·(Y+1) df}.

A1.2.3.4 To obtain confidence limits for structure loading, the confidence limit for the mean of the number of structures

TABLE A1.1 Spreadsheet Formulae to Calculate Upper and Lower 95 % Confidence Limits

	A	B	C
1	Number of Structures Counted	95 % LCL (structures)	95 % UCL (structures)
2	1	=(IF(A2>0,(CHIINV(0.975,2·A2)/2),0))	=(IF(A2>0,(CHIINV(0.025,2·(A2+1))/2),(CHIINV(0.05,2)/2)))

TABLE A1.2

Confidence Limit	α
90 %	0.10
95 %	0.05
99 %	0.01

must be multiplied by the sensitivity of the measurement. This can be easily calculated using spreadsheet functions.

(1) For example, in the Microsoft spreadsheet program Excel the following expression can be used:

(a) To obtain the upper 1-α level confidence limit: =IF(A2>0,(CHIINV(α/2,2·(A2+1))/2),(CHIINV(α,2)/2)), where the value in cell A2 is the observed count of structures.

(b) To obtain the lower 1-α confidence limit: =IF(A2>0,(CHIINV(1-α/2,2·A2)/2),0), where the value in cell A2 is the observed count of structures. Table A1.1 provides an example of the formulae in an Excel spreadsheet necessary to calculate the lower and upper 95 % confidence limits.

(2) The confidence limits associated with the significance level α is equal to 1-α. As such, Table A1.2 gives the α for various confidence limits.

(3) The number of structures at the upper and lower confidence limit is multiplied by the sensitivity of the measurement to obtain the upper and lower 1-α confidence limits for asbestos structure loading based on one sample.

A1.2.4 *Interpretation of Estimate and Confidence Limits:*

A1.2.4.1 The value computed in A1.2.1 is an estimate of the mean (expected value of the Poisson distribution) of asbestos structure loading for the homogeneous area where the sample was collected. The values calculated in A1.2.2 are confidence limits for the mean (expected value of the Poisson distribution) of asbestos structure loading for the homogeneous area where the sample was collected.

A1.3 *Asbestos Surface Loading Estimated from Multiple Samples Collected by Test Method D5755*:

A1.3.1 The measurements for multiple samples, say n samples, collected from a homogeneous area may be combined to produce an estimate of asbestos surface loading for the homogeneous area that is more precise than an estimate of asbestos surface loading based on one sample. The individual measurements are averaged using a weighted average where the sensitivities of the individual samples determine the weights.

A1.3.1.1 Given n measurements {(Si, Xi, Wi): i = 1, 2, …, n}, the structure loadings are {Yi = Si·Xi}; the mass loadings are {Yi = Si·Wi }. (Here, the mass, Wi, is the total mass measured for the *i*th sample.) The "weights" in the weighted average are the reciprocals of the sensitivities {(1/Si)}. The weighted average has a numerator and a denominator. The numerator is the sum of "weight multiplied times measurement" for all measurements. The denominator is the sum of the weights used in the numerator. Therefore, for structure loading, the weighted average is (ΣXi)/[Σ (1/Si)]; for mass loading, the weighted average is (ΣWi)/[Σ (1/Si)]. Note when sensitivity is a constant, Si = S, the answers are simple averages – [S·(ΣXi/n)] for structure loading; [S·(ΣWi/n)] for mass loading.

A1.3.2 *Data for Multiple Samples:*

A1.3.2.1 {STRi, Si: I = 1, 2, … , n} are the structure counts and sensitivities of the n samples.

A1.3.3 *Estimate:*

$$STR/\mathrm{cm}^2 = \left[\sum ST_i\right]/\left[\sum (1/S_i)\right] \tag{A1.3}$$

A1.3.3.1 Note that if the sensitivities for all measurements are the same value, S, then the estimate is computed as the average structure count over the samples multiplied by S:

$$STR/\mathrm{cm}^2 = S\cdot\left(\left[\sum ST_i\right]/n\right) \tag{A1.4}$$

A1.3.4 *Confidence Limits:*

A1.3.4.1 Upper and lower confidence limits are obtained using the formulas in A1.2.2 with B2 set equal to the total number of structures counted in the n samples, [Σ STR_i].

A1.4 *Compare Two Environments* :

A1.4.1 *Compare Two Environments Using Confidence Intervals:*

A1.4.1.1 Compute separate confidence limits based on samples collected from Homogeneous Area 1 and Homogeneous Area 2. Apply the following decision rule: If the confidence intervals based on these limits overlap, conclude that the asbestos structure loadings in the two homogeneous areas are the same; if the confidence intervals do not overlap, conclude that the asbestos structure loadings in the two homogeneous areas are different. Overlap occurs when the upper confidence limit of the interval with the smaller estimated mean is larger than the lower confidence limit of the interval with the larger estimated mean.

A1.4.2 *Interpretation of Confidence Interval Test:*

A1.4.2.1 If 95 % confidence intervals are used to conduct the statistical test described in A1.4.1, the significance level for the test is approximately 0.05. In general, if 100·(1-α) % confidence intervals are used for the test described in A1.4.1, the significance level for the test is approximately α. The confidence interval test is an approximate test that yields reliable results where the overlap or separation of the intervals is large. For example, data where the confidence intervals have a small overlap indicating no statistically significant difference may show a statistically significant difference if a more precise statistical test were used. See for example "Testing the equality of two Poisson means using the rate ratio," Hon Keung Tony Ng and Man-Lai Tang, *Statistics in Medicine*, 24, 2005, pp. 955-965.

A1.4.3 *Compare Two Environments Using Normal Distribution Approximation for Poisson Count Data:*

A1.4.3.1 *One Sample from Each Environment:*

(1) The square root of a structure count has an approximate Normal distribution with mean equal to the square root of the count mean and variance equal to 0.25. Let STR_1 and STR_2 be the structure counts for two samples with sensitivities S_1 and S_2 respectively. The Z-value for testing the equality of the asbestos surface loadings for the two environments where the samples were collected is:

$$Z = [(ST_1)^{1/2} - (ST_2)^{1/2}]/[0.5 \cdot (S_1 + S_2)^{1/2}] \tag{A1.5}$$

(2) To test the null hypothesis of "no difference between mean asbestos surface loadings in the two environments" compare Z to test value 1.96 for a test with approximate significance level equal to 0.05; compare Z to 2.58 for a test with approximate significance level equal to 0.01. Reject the null hypothesis if Z is larger than the test value.

A1.4.3.2 *Multiple Samples from Each Environment:*

$$Z = [(ST_1/\mathrm{cm}^2)^{1/2} - (ST_2/\mathrm{cm}^2)^{1/2}]/\{0.5 \cdot ([1/\sum(1/S_{1i})] + [1/\sum(1/S_{2i})])^{1/2}\} \tag{A1.6}$$

where $STR_i/\mathrm{cm}^2 = [\sum ST_{ij}]/[\sum(1/S_{ij})] \quad i = 1, 2; \quad j = 1, 2, \ldots, n_i$

(1) The subscripts "1" and "2" indicate measurements for samples from the two different environments that are compared. (Refer to A1.3 for definitions of the notation.) Z is used to test the null hypothesis of "no difference between mean asbestos surface loadings in the two environments" as described in A1.3.1.

A1.4.3.3 *Example*—Test described in A1.4.3.2 applied to Example 2 in main body of the guide. (See Table A1.3.)

(1) From Table 2 in 6.10 in the main body of the guide we have:

$$ST_1/\mathrm{cm}^2 = 3508; \; ST_2/\mathrm{cm}^2 = 2133 \tag{A1.7}$$

$$\text{Sum of Sensitivity Weights } S_1 = 0.014821 \text{ and } S_2 = 0.024377$$

(2) This makes the denominator in the Z ratio = 0.5·((1/0.010205)+(1/0.02439))$^{1/2}$ = 5.2080.

(3) Therefore:

$$Z = (59.23 - 46.19)/5.2080 = 2.5 \tag{A1.8}$$

(4) Since the statistical hypothesis being tested is a two-sided hypothesis, mathematical notation for the p-value is 2·[1 − Φ(Z)], where Φ(·) is the standard normal distribution. Therefore the p-value is calculated with the formula:

$$2 \cdot [1 - \Phi(Z)] \tag{A1.9}$$

TABLE A1.3

Number of Structures Counted in Study Samples	Sum of Sensitivities for Study Area Measurements	Number of Structures Counted in Background Samples	Sum of Sensitivities for Background Area Measurements
52	0.014821	52	0.024377
Z = 2.5		p-value = 0.012	

TABLE A1.4

Confidence Interval	Z	p-value
99 %	2.56	≤0.01
95 %	1.96	≤0.05
90 %	1.64	≤0.10

(5) The p-value can be calculated using spreadsheet functions. For example the following expression in Microsoft's Excel spreadsheet program will calculate the p-value where Z is known:

$$2 \cdot (1 - \mathrm{NORMSDIST}(Z, 0, 1, \mathrm{TRUE})) \tag{A1.10}$$

(6) The p-value for the Z in this example is 0.012 and as this p-value is less than 0.05, as is described in 6.10.2.1 the two areas are considered to be different. Table A1.4 gives Z and the p-value for various confidence intervals.

A1.4.4 Additional details concerning statistical tests for Poisson data are provided in "Testing the Equality of Two Poisson Means Using the Rate Ratio," Hon Keung, Tony Ng, and Man-Lai Tang, *Statistics in Medicine*, 24, 2005, pp. 955-965; and *Statistical Rules of Thumb*, Wiley, 2002.

A1.5 *Identification and Control of Sources of Variation*:

A1.5.1 Differences in collection efficiency which could affect comparisons are discussed in Appendix X1.

A1.6 *Sample Locations*—One method of determining where to sample using a random number table is described below.

A1.6.1 The investigator wishes to collect samples from 20 metal desks. The 20 metal desks are given number 01, 02, …19, 20. Beginning in the middle of a random number table, the investigator separates the numbers into 2-digit values. The first six pairs might be 88, 26. 14, 06, 72, and 96. Since the numbers 14 and 06 correspond to the numbers assigned to the desks, two of the desks have been chosen for sampling. This process continues until 5 different desks (or the number of samples as determined below) have been selected.

A1.6.2 This same process is repeated to select the location on the top surface of each desk selected. An imaginary grid of 9 equal areas is constructed on each desk top and numbered 10-19. Again, from the random number table the investigator selects 2-digit numbers until one pair of numbers matches one of the grid numbers. If the 2-digit pairs are 66, 24, 42, and 12; then the grid corresponding to "12" is where the sample will be collected for that desk.

A1.7 *Sets of Samples*:

A1.7.1 One set of samples should be collected to characterize the asbestos dust loadings for each different type of homogeneous surface being tested. For example, if the sampling was being conducted following a cleaning the following could apply.

A1.7.2 If workers followed the same cleaning procedure for a group of 10 desks, 20 filing cabinets and 12 bookcases all constructed of metal then may be grouped together as "metal furniture." However, if 5 of the desks had leather tops, these 5 would be sampled as a separate set, or could be combined with other leather surfaces.

A1.7.3 If 40 desks were cleaned; 20 of which were wet-wiped, and 20 were HEPA vacuumed, these would be separated into two groups of 20 desks for sampling since the cleaning methods were significantly different.

A1.8 *Number of Samples*—The number of samples used to test for a difference between the asbestos surface loading in two environments determines the power of the statistical test. For a fixed number of samples, the power of the test, which is the probability that a specified difference between the asbestos surface loadings will be detected by the test, varies with *(1)* the magnitude of the difference to be detected and *(2)* to some extent with the significance level of the statistical test. To determine the number of samples for a test, this relationship would be inverted. The significance level and power would be specified as would the corresponding magnitude of difference that should be detected by the test with appropriate probability (that is, power). These quantities, then, would be used to determine the number of samples.

A1.8.1 *Base Case—Rule of Thumb:*

A1.8.1.1 For this base case, the number of samples collected from each environment will be the same, n, and the sensitivities of each measurement will be the same, S. (Even though planning for sampling and analysis may specify a constant sensitivity for all measurements, sensitivities may vary during implementation of the plan due the need for dilution when analyzing the samples. For the current discussion, it is assumed that if dilution becomes necessary, it was anticipated at the planning stage and incorporated into the sensitivity value used for the plan.) The statistical test addresses a two-sided alternative (that is, if the asbestos surface loadings are not equal in the two environments, the larger asbestos surface loading may be occur in either of the environments). The significance level of the test is 0.05 and the power of the test is 0.80. Then, the number of samples required is:

$$n = 4 \cdot S / \{[(ST_1/\text{cm}^2)^{1/2} - (ST_2/\text{cm}^2)^{1/2}]^2\} \qquad (A1.11)$$

(1) STR_1/cm^2 is the hypothesized mean structure concentration in environment 1 for planning purposes.

(2) STR_2/cm^2 is the hypothesized mean structure concentration in environment 2 for planning purposes.

A1.8.2 *Example Table*—Number of samples required for testing the difference between two environments where the significance level of the test is 0.05 and the power of the test is 0.80. (See Table A1.5.)

A1.8.3 Number of samples required in each environment when the significance level for testing the difference between environments is 0.05. (See Table A1.6.)

A1.8.3.1 The general equation for determining the number of samples to achieve a test with significance level equal to α and power equal to 1-β where sensitivities for all measurements are the same value and the number of samples collected from each environment are equal is:

$$n = (0.5) \cdot (Z_{1-\alpha/2} + Z_{1-\beta})^2 \cdot S / \{[(ST_1/\text{cm}^2)^{1/2}]^2\} \qquad (A1.12)$$

(1) $Z_{1\text{-}\alpha/2}$ is the 100·(1-α/2) percentile of the Standard Normal distribution and $Z_{1\text{-}\beta}$ is the 100·(1-β) percentile of the Standard Normal distribution.

A1.8.4 The sample size formula presented in A1.8.1 is appropriate for the statistical test described in A1.4.3.2. For sample size determination associated with other statistical tests refer to "Power Calculation for Non-Inferiority Trials Comparing Poisson Distributions," which is available from www.lexjansen.com/phuse/2005/pk/pk01.pdf.

TABLE A1.5

Sensitivity Environment 1	Sensitivity Environment 2	Hypothesized STR/cm^2 Environment 1	Hypothesized STR/cm^2 Environment 2	Number of Samples in Each Environment (n)
200	200	5000	1000	1
2000	2000	5000	1000	5
10 250	10 250	5000	1000	27
200	200	2000	1000	5
2000	2000	2000	1000	47
10 250	10 250	2000	1000	239

TABLE A1.6

Measurement Sensitivity	HypothesizedSTR.cm^2		Number of Samples Required in Each Environment		
Both Environments	Environment 1	Environment 2	Power Equal to 0.80	Power Equal to 0.95	Power Equal to 0.99
200	5000	1000	1	1	1
2000	5000	1000	5	9	12
10 250	5000	1000	26	44	62
200	2000	1000	5	8	11
2000	2000	1000	46	76	107
10 250	2000	1000	234	388	549

TABLE A1.7 Attachment 1: Upper and Lower 95 % Confidence Limits for the Poisson Distribution

0–50			51–100			101–150		
Number of Structures	95% LCL (s/cm^2)	95% UCL (s/cm^2)	Number of Structures	95% LCL (s/cm^2)	95% UCL (s/cm^2)	Number of Structures	95% LCL (s/cm^2)	95% UCL (s/cm^2)
1	0	6	51	38	67	101	82	123
2	0	7	52	39	68	102	83	124
3	1	9	53	40	69	103	84	125
4	1	10	54	41	70	104	85	126
5	2	12	55	41	72	105	86	127
6	2	13	56	42	73	106	87	128
7	3	14	57	43	74	107	88	129
8	3	16	58	44	75	108	89	130
9	4	17	59	45	76	109	90	131
10	5	18	60	46	77	110	90	133
11	5	20	61	47	78	111	91	134
12	6	21	62	48	79	112	92	135
13	7	22	63	48	81	113	93	136
14	8	23	64	49	82	114	94	137
15	8	25	65	50	83	115	95	138
16	9	26	66	51	84	116	96	139
17	10	27	67	52	85	117	97	140
18	11	28	68	53	86	118	98	141
19	11	30	69	54	87	119	99	142
20	12	31	70	55	88	120	99	143
21	13	32	71	55	90	121	100	145
22	14	33	72	56	91	122	101	146
23	15	35	73	57	92	123	102	147
24	15	36	74	58	93	124	103	148
25	16	37	75	59	94	125	104	149
26	17	38	76	60	95	126	105	150
27	18	39	77	61	96	127	106	151
28	19	40	78	62	97	128	107	152
29	19	42	79	63	98	129	108	153
30	20	43	80	63	100	130	109	154
31	21	44	81	64	101	131	110	155
32	22	45	82	65	102	132	110	157
33	23	46	83	66	103	133	111	158
34	24	48	84	67	104	134	112	159
35	24	49	85	68	105	135	113	160
36	25	50	86	69	106	136	114	161
37	26	51	87	70	107	137	115	162
38	27	52	88	71	108	138	116	163
39	28	53	89	71	110	139	117	164
40	29	54	90	72	111	140	118	165
41	29	56	91	73	112	141	119	166
42	30	57	92	74	113	142	120	167
43	31	58	93	75	114	143	121	168
44	32	59	94	76	115	144	121	170
45	33	60	95	77	116	145	122	171
46	34	61	96	78	117	146	123	172
47	35	63	97	79	118	147	124	173
48	35	64	98	80	119	148	125	174
49	36	65	99	80	121	149	126	175
50	37	66	100	81	122	150	127	176

APPENDIX

(Nonmandatory Information)

X1. FACTORS AFFECTING SAMPLE COLLECTION

X1.1 There are a number of factors which can affect sample collection and design of a sampling strategy. Care should be exercised in the selection of sample locations to ensure that differences in results are reflective of actual differences in the level of asbestos rather than being due to differences in collection efficiency. Dust as defined in the ASTM methods consists of particles that are less than or equal to one millimeter in size and than can pass through a one millimeter screen during the analysis. Particles larger than this are considered debris and should not be picked up during the sample collection. If particles larger than one millimeter are encountered then either a different sampling location should be selected, or the particles of debris should be carefully removed from the sample area and analyzed separately as a bulk sample.

X1.2 *Uniformity of Dust Loading* —When selecting sample sites for homogenous samples make a visual determination that the dust loading on surfaces is uniform. The dust loading on surfaces can vary due to a number of factors.

X1.2.1 If samples are to be collected in an area, such as above ceilings, that are not subjected to routine cleaning make a determination that all surfaces sampled were installed at the same time and make a visual determination that the dust loading on the surface has not been disturbed. For example, if sampling is to be conducted on top of light fixtures, a replacement light fixture or one that has been relocated may have a different dust loading from the loading to be expected on an original light fixture, or one that has not been relocated.

X1.2.2 If samples are to be collected from surfaces that are infrequently cleaned, such as the top of door frames or other trim, make a determination that all samples are collected from areas that have the same cleaning history and dust loading. Typically this will require interviewing facility staff about cleaning practices, and correlating this information with observations of dust loadings on surfaces.

X1.2.3 Observe the dust loading on surfaces to determine if it is visually uniform. Dust loadings within a given area can be heavier in areas of return air collection, near windows, or near air supply outlets.

X1.2.4 Settled dust loadings will typically be heavier in areas such as entry halls, near frequently open windows (particularly on lower floors), and locations where dust-producing activities such as machine handling of paper occur.

X1.2.5 Settled dust loading may accumulate more rapidly in areas where there is greater activity to disturb asbestos-containing materials.

X1.2.6 The dust loading above ceilings where the space above the ceiling is used as a return air plenum may be in a gradient corresponding to the volume and velocity of return air. Dust loading may be concentrated in areas where there is a change in direction of return air. There may be a localized increase in dust loading in any location where there is turbulence.

X1.2.7 Obstructions located in an air stream will generally have a higher dust loading than surrounding surfaces. For example, a grill over a return air intake will normally have a higher dust loading than surrounding areas. The amount of dust collected on a grill will be affected by the volume and velocity of air flow, design of the grill, amount of turbulence, and amount of dust in the air stream.

X1.3 *Dust Characteristics*—When selecting sample sites for homogenous samples make a visual determination that the observable characteristics of the dust are similar. Dusts from different sources can have differing characteristics that may affect either collection efficiencies or analysis.

X1.3.1 Highway dust in urban areas or in buildings near busy highways can have a high soot and rubber dust content. This makes the dust sticky and difficult to collect by vacuum methods. Consider using Test Method D6480 for these areas.

X1.3.2 Dust from activities that disturb paper including copying, collating, or manual handling of papers or books. These activities can produce dust that is light in weight and fluffy but that tends to ball up and is easily compressed into felt or pellets. This dust is light and easily collected from surfaces, but if compressed by handling or contact it can become felted and more difficult to collect.

X1.3.3 Fibers worn from carpeting and clothing and hairs from occupants or pets tend to collect and form balls with dust. This may affect the uniformity of dust deposition on a surface.

X1.3.4 Consider using wipe sampling (Test Method D6480) if problems with micro-vacuuming (Test Methods D5755 and D5756) are encountered, such as for dust on wet surfaces and dust that has been wetted, etc.

X1.4 *Surface Characteristics* —When selecting sample sites for homogenous samples make a visual determination that the surfaces from which samples are collected have similar physical characteristics. The efficiency of dust collection is a complex function of the characteristics of the collection method and the characteristics of a surface as well as the interactions between them. Similar surfaces from different manufacturers may differ from each other in the ease with which they release dust for collection, as may surfaces installed by craftsmen such as brick masons and plasters. Table X1.1 lists some surface types that may differ from each other in the ease with which they release dust for collection.

X1.5 *Past Disturbances of Asbestos-Containing Material (ACM)*—If there has been a disturbance of an

TABLE X1.1 Surface Characteristics and ASTM Sampling Methods

Surface Characteristics	D5755 Microvacuum Number Loading and D5756 Microvacuum Mass Loading	D6480 Wipe Number Loading
Hard smooth surfaces such as painted metal or wood	Yes	Yes
Hard textured surfaces such as unpainted wood or sand-finished concrete or plaster	Yes	Possible
Hard irregular surfaces such as brick or rough concrete	Yes	No[A]
Hard plastic surfaces or other surfaces that can develop a static charge	Possible	Yes
Hard porous surfaces such as mineral fiber board ceiling tile tops	Yes	Possible
Soft smooth surfaces such as vinyl upholstery or wall coverings	Yes	Yes
Soft textured surfaces such as cloth upholstery on furniture or office partitions	Yes[B]	Possible[B]
Soft irregular surfaces such as carpeting or fibrous glass	Yes[B]	No[A]

[A] Collection may be possible from these surfaces under some circumstances.

[B] Method is less efficient at collecting dust from these surfaces than on smooth surfaces.

asbestos-containing material that has resulted in the release of asbestos containing dust and debris, there may be an increase in the loading of asbestos in dust in the vicinity of the disturbance. This increase may be localized and there may be a gradient in loading with the level decreasing as the distance from the disturbance increases. The sampling plan and reported results need to clearly set forth the manner of dealing with past disturbances.

X1.5.1 A clear distinction should be made between samples of settled dust collected in areas remote from any observable disturbance of ACM and samples collected in the vicinity of a disturbance. This is particularly true of a sample collected directly below the site of a disturbance. Remote samples are more likely to represent background conditions within a structure. Samples collected near, or directly below, a disturbance are more likely to represent the consequence of the disturbance, and may not be related to background.

X1.5.2 *Single Disturbance*—If there has been a single disturbance the sampling plan should allow for the evaluation of a possible gradient in the loading of asbestos in the dust. Ideally, sufficient samples should be collected at varying distances from the disturbance so that the spatial distribution of asbestos loadings can be characterized. If this is not possible, samples should be collected either at the center of the disturbance to characterize the maximum loading resulting from the disturbance, or should be collected at a location sufficiently remote from the disturbance to represent background conditions. In these instances the sampling plan and reported results should specifically indicate whether the goal is to determine localized elevations in levels or background conditions. The location of samples in relation to the disturbance should be clearly identified.

X1.5.3 *Multiple Disturbances*—If there have been a number of disturbances of various magnitudes throughout an environment the loading of asbestos in the dust may be non-uniform. The loading may be higher near a disturbance and lower in areas remote from disturbances.

X1.6 A relatively uniform distribution of loadings due to random disturbances may be produced, if there have been a large number of disturbances that are relatively close together, uniformly distributed spatially and of the same magnitude. Under these circumstances a random sampling may produce an acceptable level of precision. Care should be used in developing the sampling plan and interpreting results, so that true differences in loadings are not interpreted as random errors. Such a misinterpretation can lead to a sufficiently large variation in sample results that comparisons to other environments or to standards may be difficult or impossible. In a facility past disturbances of ACM may be localized and of different magnitudes. Under these circumstances, a random sampling that treats disturbances as random events evenly distributed throughout the sampled area may result in a mean that is not representative of loadings prevalent in the area, and there may be an unacceptably large variation in sample results. It may be necessary to develop a sampling plan that aims at defining the spatial distribution of loadings, or each disturbance may need to be considered as a separate event.

X1.6.1 Samples collected directly beneath a disturbance of ACM should be considered as representative of the fall-out resulting from the disturbance rather than being representative of settled dust with the facility.

X1.7 *Disturbance During Sample Collection*—Disturbance of facility components during sample collection could alter the deposition of dust being sampled and compromise the result. For example, if disturbing a ceiling tile is suspected of causing a release of airborne ACM dust and debris, this could affect samples in the vicinity that are intended to be representative of long-term accumulations.

X1.8 *Environmental Conditions* —Samples should be collected in locations with similar environmental conditions. Differences in temperature, humidity, and ventilation may produce differences in the rate of dust deposition and efficiency of sample collection. Areas that are exposed directly or indirectly to the weather should be considered separately from interior areas.

X1.9 *Ventilation*—Ventilation patterns can affect the rate of deposition of dust and its distribution within a space.

X1.9.1 The quantity, type and source of dust may differ in spaces served by different air handling units. In buildings with central heating, ventilating, and air conditioning (HVAC) equipment the return air from individual spaces will be mixed. Some of this return air will be exhausted from the building and fresh air added to make up the difference. The mixture of fresh and return air is heated or cooled, filtered and returned to the building as supply air. The proportion of fresh and return air in the supply air will vary as outside conditions and their relation to interior heating and cooling loads change. As a result of this the amount and source (interior or outdoor) of dust carried by supply air can vary between air handling units. Where there are individual units for each space there can be different conditions in each room.

X1.9.2 The operation of a ventilation system can preferentially increase the proportion of larger particles ("larger" is defined as having a larger aerodynamic equivalent diameter) in a space. Dust introduced with incoming supply air will tend to settle out of the air stream when it slows after leaving supply diffusers. Dust may be generated by activity in the space or come from materials in the space. The larger particles will settle to surfaces more rapidly than the smaller particles. The smaller particles will be removed from the space with return air more efficiently than the larger particles. Differences in ventilation rates for individual rooms can create not only differences in overall dust loading, but also in the type and source of dust found in the room. The rate of return air from a space can affect the rate of dust deposition and the type of dust. The distance from supply and return air points can affect the proportion of small and large particles in a space as can the level of activity. Larger particles will be re-suspended in a room with greater activity so that they will be removed with return air at a greater rate than in a room with less activity.

X1.9.3 If the room has more supply air than return air it will operate at a positive pressure relative to surrounding areas. This could cause the dust in the space to be more strongly influenced by the dust arriving with incoming supply air or generated in the space than by dust in surrounding spaces. In the opposite condition where the return air collection exceeds the amount of supply air the space will be at a negative pressure and will tend to collect air and dust from surrounding areas.

X1.9.4 Dust located in the direction of return airflow has a higher probability of being influenced by conditions and activities in a space, than does dust related to supply air. Supply air is a mixture of re-circulated and fresh outside air. In buildings with central air handling equipment, re-circulated air can come from areas of the building remote from the area being investigated. Dust in the location of supply air will be more strongly affected by outdoor conditions and the quality of filtration in the air handling equipment. Fresh air from outside of the building will be introduced into supply air, so that dust in the locations of supply air inlet will be more reflective of outdoor conditions, than dust found in the return air path. The effect of outdoor air will be greater during times of the year when natural ventilation is greatest (typically during mild weather), and in spaces with greater ventilation rates such as assembly spaces.

X1.9.5 The distinction between the nature of dust associated with supply and return air paths will be more distinct in a well-sealed building with fixed windows that is maintained at a higher air pressure than outside to prevent infiltration. In buildings with a great deal of air infiltration or where windows are opened for ventilation unfiltered outside air will be introduced directly into the occupied space.

X1.9.6 The overall nature of dust in a building will be influenced by maintenance of the air handling systems. Poor quality, damaged or missing filters can result in building dust that is more strongly related to outdoor dust loadings. Extremely poor maintenance can result in hydrocarbon dust from motors and belts.

X1.10 *Building History*—Overall dust loadings and the asbestos loading of dust can be affected by past activities within a facility.

X1.10.1 *Past Disturbance of ACM*—If there has been a past disturbance of ACM in a space there may be an increase in the asbestos loading in the dust in that space that may differ from other locations in the building.

X1.10.2 *Asbestos Abatement Projects*—Past asbestos abatement projects could decrease or increase the loading of asbestos in dust in the abated space and surrounding areas.

X1.10.3 Past renovation projects create dust and also remove or change surfaces. Make sure that all surface samples have the same history of residence in the facility. Maintenance work such as painting can produce different residency periods for dust loadings.

X1.10.4 *Cleaning History*—Different parts of the building may be cleaned differently, with different methods or with different frequency leading to differences in overall dust loadings. For example, carpets are vacuum cleaned while bathrooms are wet cleaned, and this can produce a difference in the dust loading associated with these two types of spaces. High areas such as the top of door frames may be cleaned on different schedules in different areas. Offices may be subjected to a periodic "spring cleaning" while storage areas may never be cleaned.

X1.10.5 *Occupation*—If different parts of the building have different occupancies the dust loading may be affected. For example a kitchen, printing shop, day care center, and office could all have different types of dust in different loadings. Within a single occupancy structure the predominant use of a space can affect its dust loading and the type of dust found. For example, a commercial kitchen is frequently cleaned and may have lower overall dust loadings than the balance of the building. Kitchens usually have a great deal of exhaust ventilation. This will result in either an increase in outside air resulting in an influence by outdoor conditions, or an increase in makeup air from the building leading to the dust type being more influenced by surrounding areas of the building. Grease found in kitchens can affect sample collection efficiency.

X1.11 *Outdoor Samples*—Care should be used in attempting to compare interior and outdoor samples. In most instances outdoor sample locations will have been affected in some manner by exposure to the elements. Even surfaces that are not exposed to the weather will have experienced different climatic conditions from interior sample locations.

X1.11.1 Outdoor surfaces can be affected by adjacent sources of asbestos. Demolition of adjacent buildings, automobile braking and asbestos in soil can increase outdoor asbestos dust loadings.

X1.11.2 Weathering or exposure to rain, snow or ice will tend to clean surfaces of dust and thus reduce overall dust loadings. Locations where runoff collects and puddles may have locally elevated dust loadings.

X1.11.3 Outdoor surfaces may be periodically dampened by mist, high humidity, dew, or condensation. Dust will tend to cake on surfaces that are periodically dampened, and may not be collected as well as from interior surfaces.

X1.11.4 Samples collected in areas such as sills of operable windows, doors, and near exhaust vents, could be affected by past disturbance of ACM in the building.

X1.11.5 Dust collected on the interior surfaces of fresh air intake air louvers, ductwork or in fresh air plenums may have a higher index of asbestos than outdoor ambient due to the forced collection of outside air. The amount of dust collected in these areas will be greater than outdoor ambient dust so that the index in terms of asbestos structures counted or mass of asbestos structures per unit area will be increased above outside ambient dust. However, the loading of asbestos in the dust in these locations should be representative of the dust in the fresh air being brought into the building for ventilation.

X1.11.6 The steep asphalt used in the construction of flashings on built-up roofs usually contains asbestos. This is true even in roofs of recent construction. The surface of this asphalt is degraded to a powder by the sun, and this powder may have an asbestos content. The powder will be carried by water over the surface of the roof. Therefore, dust on built up roofs can contain asbestos from asphalt. Some roofing felts are made of asbestos. If the asphaltic coating on these felts is weathered away the felts may become weathered and thus contribute to the asbestos loading of dust found on the roof. Deterioration of adjacent roofs can affect the asbestos loading of dust found on the outside of a building.

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