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Guidelines for Conducting the AHERA TEM Clearance Test to Determine Completion of an Asbestos Abatement Project

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FINAL REPORT

GUIDELINES FOR CONDUCTING THE AHERA TEM CLEARANCE TEST TO DETERMINE COMPLETION OF AN ASBESTOS ABATEMENT PROJECT

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SUMMARY

Asbestos abatement carried out in schools is subject to regulations under the Asbestos Hazard Emergency Response Act of 1986 (AHERA). The AHERA rule (40 CFR Part 763) includes procedures for determining when an asbestos abatement site is sufficiently clean for the containment barriers to be removed. After the abatement site has been subject to a thorough visual inspection, air samples are collected. In most cases, the samples must be analyzed by transmission electron microscopy (TEM).

This document provides guidance for conducting the TEM clearance test with emphasis on interpretation of the results. The three components of the test -- the Initial Screening Test, the Blank Contamination Test, and the Z-test -- are described and illustrated with numerical examples.

1. INTRODUCTION

As required under the Asbestos Hazard Emergency Response Act of 1986 (AHERA), EPA has promulgated a rule regarding inspections, abatement, and management of asbestos-containing material in schools (40 CFR Part 763). The rule includes procedures for determining when an asbestos abatement site is sufficiently clean for the containment barriers to be removed. After the abatement site has been subject to a thorough visual inspection, air samples are collected. In most cases, the samples must be analyzed by transmission electron microscopy (TEM).

This document provides guidance for conducting the TEM clearance test with emphasis on interpretation of the results. The guidance is intended for abatement project monitors, industrial hygienists, asbestos consultants and others who are responsible for interpreting air sampling data. Details on sampling and analytical protocols are not included. Readers should refer to the AHERA rule for details on these topics and to determine the circumstances under which alternative clearance procedures may be used. Readers are also urged to consult the latest version of the AHERA rule for revisions that may have been made since the publication of this document.

2. BACKGROUND

The AHERA TEM clearance test is based on a comparison of airborne asbestos levels inside the work site with those outside the work site. This approach was adopted since an abatement contractor could not be expected to achieve airborne asbestos concentrations inside the work site lower than those of the incoming air. "Outside" does not necessarily mean outdoors. When air intake to the work site is from other parts of the building rather than from outdoors, indoor samples may be collected as the basis for comparison. However, outdoor samples are recommended in most circumstances because they are unlikely to be affected by poor work practices that might contaminate areas outside the work site.

Airborne asbestos measurements are subject to variation due to variability of the distribution of asbestos in the air and variability introduced by the sampling and analytical procedures. The clearance test must account for both sources of variation in order to achieve a high probability of correct clearance decisions. Therefore the test requires a minimum of five samples collected inside the work site and five samples collected outside the work site, and uses a statistical test, the Z-test, to determine if inside levels are statistically higher than outside levels. The Z-test differs slightly from the t-test recommended in previous EPA guidance documents (USEPA 1985a, 1985b) by fixing the amount of variability associated with the measurements rather than estimating it from the data. Consequently, the Z-test is simpler to calculate.

The Z-test is preceded by two preliminary tests, an initial screening test and a blank contamination test. The initial screening test is intended to reduce the cost of analysis when the concentration of asbestos structures on sample filters collected inside the work site is comparable to the concentration typically observed on blank filters (filters through which no air has been drawn). Asbestos structures on blank filters may be the result of contamination during filter manufacture, for example. If the concentration on filters used to sample inside the work site is comparable to typical blank contamination levels, the work site passes the clearance test without requiring analysis of the outside samples. The initial screening test is based on the concentration per area of filter, not concentration per volume of air, because it considers asbestos structures from sources other than the sampled air. Filter concentrations less than or equal to 70 s/mm^2 are considered indistinguishable from blank contamination levels. A measurement within this range suggests that few, if any, asbestos structures have been contributed by the sampled air.

If the average filter concentration for the inside samples is greater than 70 s/mm^2, a minimum of three blanks are checked to insure that the particular filter lot used was not contaminated beyond typical levels. Like the initial screening test, the blank contamination test is based on structures per area of filter because it involves asbestos structures from sources other than the sampled air.

Together, the three tests (the initial screening test, the blank contamination test, and the Z-test) make up the AHERA TEM clearance test.

3. SAMPLING

Sampling must be performed by a qualified individual who is completely independent of the abatement contractor. Although the AHERA rule does not impose specific requirements, it is suggested that the person should be professionally licensed and/or have received relevant training.

Since circumstances vary among abatement sites, professional judgment is needed to ensure that the samples accurately represent airborne asbestos levels inside and outside the work site. This section provides guidance on the number and location of samples. Refer to Section III B of the AHERA rule and USEPA (1985b) for further details on the sampling protocol.

3.1 Number of Samples

The clearance test requires a minimum of five samples inside the work site, five samples outside the work site, and three blanks. Additional samples will improve the performance of the clearance test (i.e., increase the probability of making a correct clearance decision). Additional samples are recommended for large or complex work sites that consist of several rooms or distinct areas. Provided the minimum requirements are met, it is not necessary to have an equal number of samples inside and outside the work site.

For example, if the work site consists of eight adjacent rooms, the local educational authority (LEA) may choose to collect a sample in each of the eight rooms and five samples outside the work site. The additional three samples inside the work site improve the performance of the clearance test and also provide extra assurance that each room has been adequately cleaned. If the work site fails the clearance test, the additional samples may help isolate the problem to one or more rooms and indicate where cleaning efforts should be concentrated. Note, however, that the entire work site must be resampled, not just the room or area in which high concentrations were measured during the original test.

The desirability of exceeding the minimum requirements, especially for large or complex abatement projects, should be considered when the abatement project is being planned. Specifications for sampling and interpretation of results should be clearly stated in the contract between the LEA and the abatement contractor.

The clearance test must be based on all samples analyzed. It is not permissible to analyze more than the minimum number of samples then choose the "best" results for inclusion in the calculations. It is acceptable, however, to analyze a subset of the samples collected, provided the subset of samples is selected at random without knowledge of the concentration of asbestos structures on the filters.

For example, a school district may set up 6 samplers in the work site to insure against the possibility of a lost or damaged sample. At the laboratory, 5 samples are selected at random from the 6 provided. If a sample is unsuitable for analysis, or is accidentally destroyed, the remaining sample is analyzed and the minimum of 5 samples is still achieved. If all samples are suitable for analysis and the school district decides to analyze all 6, then the results of the 6 analyses must be included in the clearance test calculations.

The AHERA rule does not explicitly address the case of samples that are so overloaded with material (asbestos or otherwise) that they cannot be analyzed by the laboratory. In most cases, an overloaded sample is indicative of a dirty work site that needs recleaning.

3.2 Location of Samples

Inside the Work Site

Samplers should be located to provide a representative sample of air within the work site. If the work site is a single room, locate the samplers throughout the area. If the work site consists of several rooms, place a sampler in each room, or in a representative subset of rooms. Random numbers may be used to select a representative subset. Each sampler should be placed so that it is subject to normal air circulation. Avoid room corners, obstructed locations, and sites near windows, doors, or vents. Ensure that the sampler is not sampling exhaust fumes from the pump. Oil droplets on the filter can adversely affect the analysis.

Outside the Work Site

Samples should be representative of air entering the work site. Place samplers so that they do not sample any air that may escape from the work site. Recommended distances are at least 50 feet from the entrance to the work site and at least 25 feet from the containment barriers. If any potential sources of fiber release (e.g., tears in the containment barrier, spillage of asbestos waste) are identified while the abatement work is in progress, these locations should be avoided when selecting the outside sampling locations.

Taking makeup air from outside the building, or passing makeup air through a HEPA filtration system before it enters the work site eliminates the need to use indoor samples taken outside the work site as the basis for comparison. The contractor no longer has to contend with other sources of airborne asbestos and should be able to clean the work site to levels comparable with outdoors. Sampling outdoors is recommended because it reduces the likelihood of the contractor improperly passing the clearance test due to poor work practices that increase airborne asbestos levels outside the work site.

Outdoor samplers should be placed at least 3 feet apart, preferably at ground level rather than on a roof. Protect the samplers from adverse weather and avoid obstructions that may influence wind patterns. If a roof-top site is necessary, avoid locations near vents or other structures.

3.3 Sample Volume

The AHERA rule specifies a minimum air volume of 560 liters for 25 mm diameter filters and 1,250 liters for 37 mm diameter filters. Recommended ranges are 1,200 liters to 1,800 liters and 2,800 liters to 4,000 liters respectively. Note that the initial screening test cannot be used when the volume of air is below the recommended range. Lower volumes require TEM analysis of a larger area of filter in order to achieve the required analytical sensitivity. This is discussed further in the next section.

4. LABORATORY ANALYSIS

Air samples are analyzed by TEM according to the protocol specified in the rule. The rule allows flexibility in the choice of volume of air sampled and the amount of filter examined, provided the analytical sensitivity (the concentration represented by a single fiber) is no greater than 0.005 structures per cubic centimeter of air (s/cc). To maintain the analytical sensitivity at 0.005 or less, a small volume of air must be compensated for by examining a larger area of the filter. Conversely, examination of a small area of the filter must be compensated for by collecting a larger volume of air.

A laboratory accreditation program for TEM analysis is being established by the National Institute of Standards and Technology (NIST, formerly the National Bureau of Standards). Only accredited laboratories will be permitted to analyze samples for compliance with AHERA. Until the accreditation program is operational, LEAs must use laboratories which follow the protocol stated in Appendix A of the rule.

5. INTERPRETATION OF RESULTS

Figure 1 shows each step in the clearance test. The initial screening test is performed first. If the inside samples pass the initial screening test, the work site passes and no further analysis is required. If the inside samples do not pass the initial screening test, the blanks are examined. If the blanks fail the blank contamination test, the source of contamination must be identified and corrected, and new samples collected. If the blanks pass the blank contamination test, the Z-test is performed to determine whether the work site passes or fails the clearance test.

The following sections describe how to perform the initial screening test, the blank contamination test, and the Z-test. The numerical examples are hypothetical and represent only a subset of the possible outcomes and decisions.

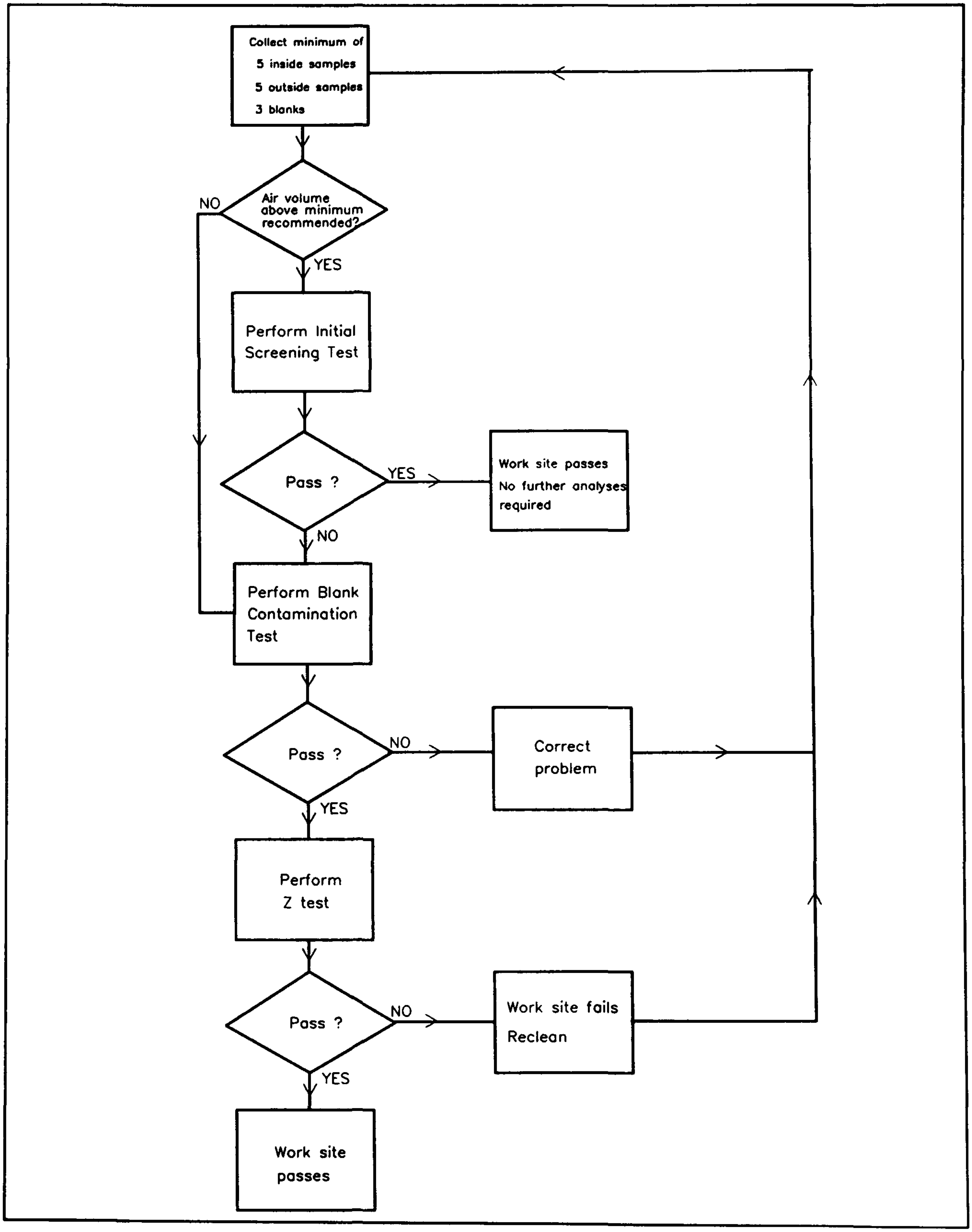


Figure 1. The AHERA TEM clearance test.

5.1 Initial Screening Test

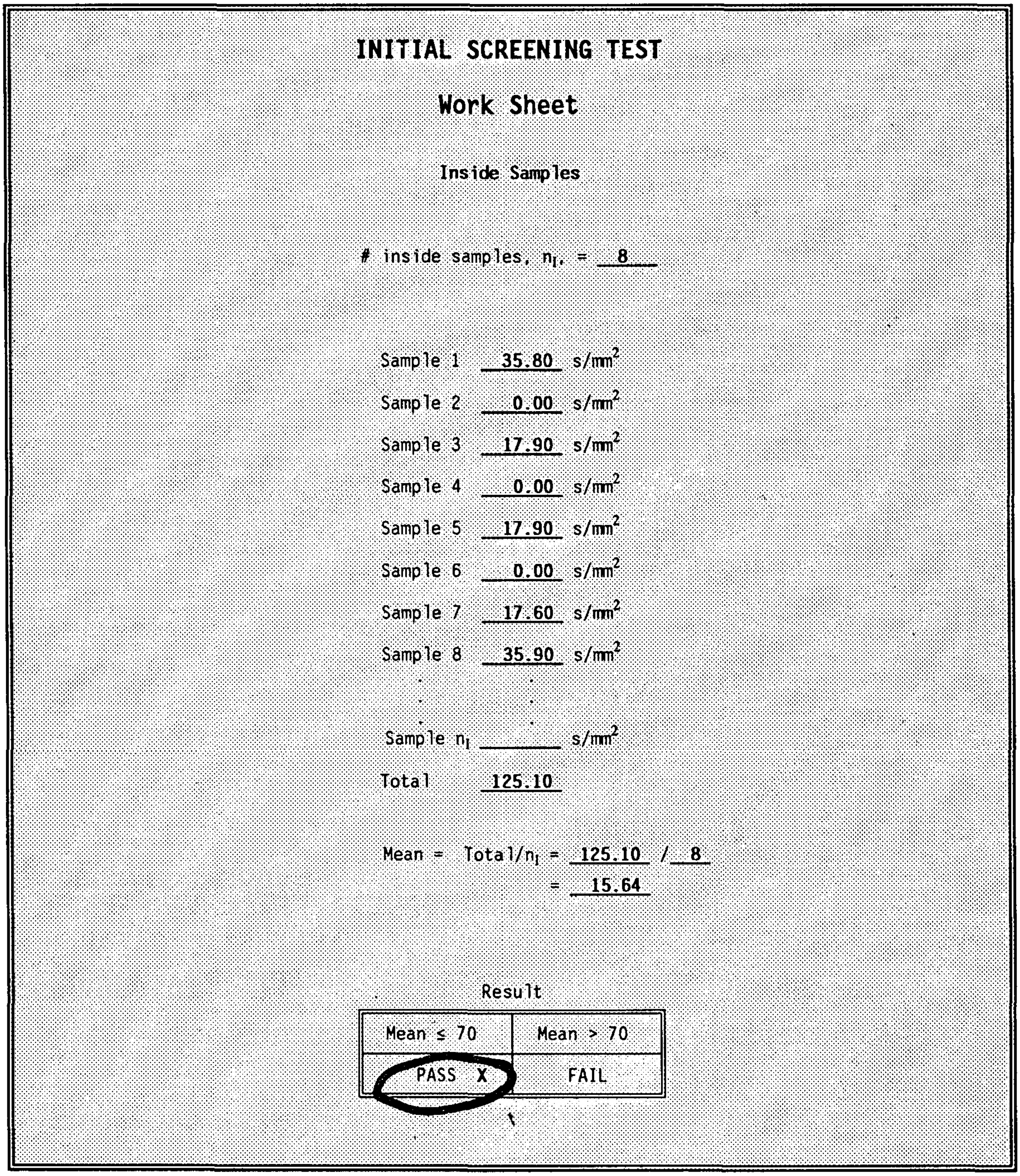
The laboratory should report the asbestos structure concentration per square millimeter of filter (s/mm^2) for each inside sample. Calculate the arithmetic mean (average) of all the inside samples. If the arithmetic mean is less than or equal to 70 s/mm^2, the inside samples pass the initial screening test and the work site passes the clearance test.

In the three examples below it is assumed that the minimum volume requirements for the initial screening test have been met. When this is not the case, the analysis proceeds directly to the blank contamination test.

Example 1. In this example the LEA decided to collect and analyze 8 inside samples. The results are shown in Figure 2. The arithmetic mean is less than 70 s/mm^2 and therefore the samples pass the initial screening test. Note that zeros are included in the calculation of the arithmetic mean. The work site passes the clearance test and no further analyses are required.

Example 2. The results of analysis of 5 inside samples are shown in Figure 3. The arithmetic mean is greater than 70 s/mm^2 and therefore the samples do not pass the initial screening test. The LEA gives the abatement contractor the option of recleaning immediately or carrying on with the blank contamination test and Z-test. The abatement contractor is convinced that the work site has been thoroughly cleaned and opts for continuing with the test.

Example 3. Five inside samples give the concentrations shown in Figure 4. The arithmetic mean is less than 70 s/mm^2 and therefore the samples pass the initial screening test. The result of the fourth analysis, however, appears to be unusually high compared with the other values. The LEA decides as a precautionary measure to ask the abatement contractor to reclean the room where the fourth sample was collected. Although this eventuality was not covered in the original contract and no action is required under the AHERA rule, the LEA decides that the additional expense is justified. (Note that there is a great deal of uncertainty associated with a single estimated concentration. That is why the clearance test requires multiple samples. Therefore caution should be used in interpreting individual values.)



INITIAL SCREENING TEST

Work Sheet

Inside Samples

inside samples, n_I, = 8

Sample 1 35.80 s/mm^2

Sample 2 0.00 s/mm^2

Sample 3 17.90 s/mm^2

Sample 4 0.00 s/mm^2

Sample 5 17.90 s/mm^2

Sample 6 0.00 s/mm^2

Sample 7 17.60 s/mm^2

Sample 8 35.90 s/mm^2

.
.
.

Sample n_I ______ s/mm^2

Total 125.10

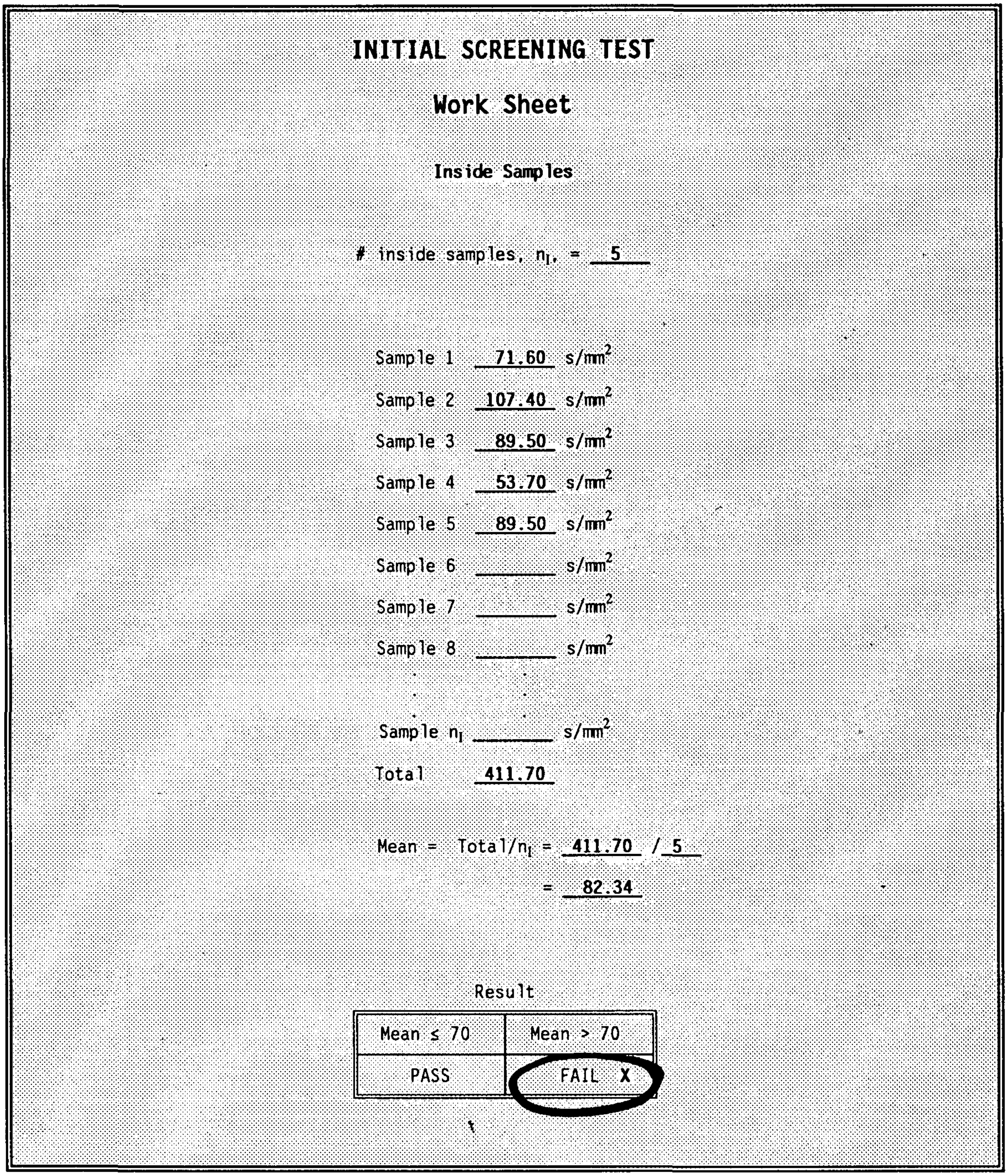
Mean = Total/n_I = 125.10 / 8

= 15.64

Result

Mean ≤ 70	Mean > 70
[✓ PASS X]	FAIL

Figure 2. The Initial Screening Test -- Example 1. In this example the work site passes and no further analyses are required.



INITIAL SCREENING TEST

Work Sheet

Inside Samples

inside samples, n_I, = 5

Sample 1 71.60 s/mm^2

Sample 2 107.40 s/mm^2

Sample 3 89.50 s/mm^2

Sample 4 53.70 s/mm^2

Sample 5 89.50 s/mm^2

Sample 6 ______ s/mm^2

Sample 7 ______ s/mm^2

Sample 8 ______ s/mm^2

.

.

Sample n_I ______ s/mm^2

Total 411.70

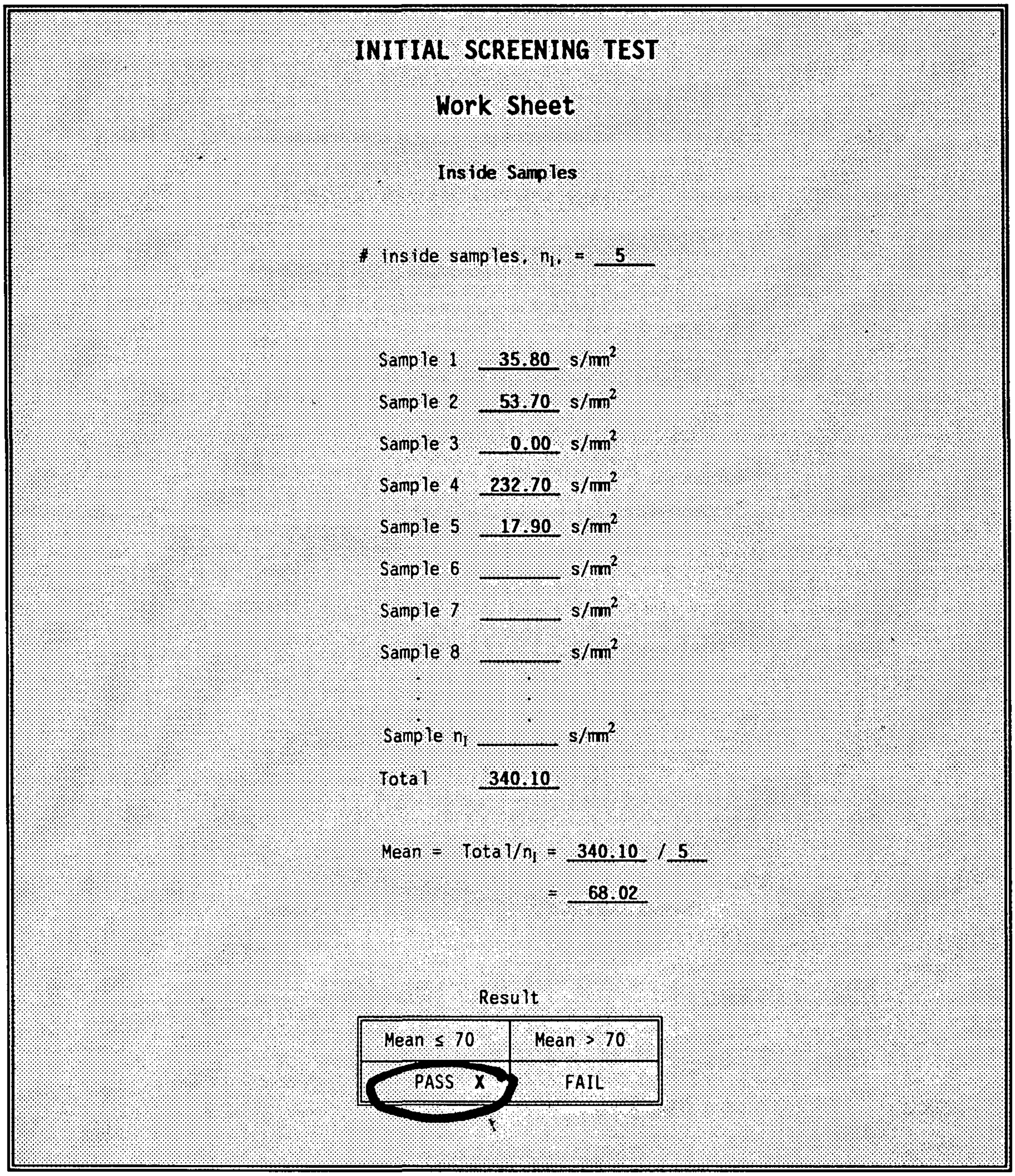
Mean = Total/n_I = 411.70 / 5

= 82.34

Result

Mean ≤ 70	Mean > 70
PASS	[✓ FAIL X]

Figure 3. The Initial Screening Test -- Example 2. In this example the work site fails. The abatement contractor, convinced that the site is clean, opts to continue with the blank contamination and Z-tests.



INITIAL SCREENING TEST

Work Sheet

Inside Samples

inside samples, n_I, = 5

Sample 1 35.80 s/mm^2

Sample 2 53.70 s/mm^2

Sample 3 0.00 s/mm^2

Sample 4 232.70 s/mm^2

Sample 5 17.90 s/mm^2

Sample 6 ______ s/mm^2

Sample 7 ______ s/mm^2

Sample 8 ______ s/mm^2

. .

. .

. .

Sample n_I ______ s/mm^2

Total 340.10

Mean = Total/n_I = 340.10 / 5

= 68.02

Result

Mean ≤ 70	Mean > 70
[✓ PASS X]	FAIL

Figure 4. The Initial Screening Test -- Example 3. In this example the work site passes and no further analyses are required under the AHERA rule. However, as a precautionary measure, the LEA decides to reclean the room where sample 4 was collected.

5.2 Blank Contamination Test

The results of the analyses of the three blanks are reported as structures per square millimeter of filter. Calculate the arithmetic mean of the three values. If the arithmetic mean is less than or equal to 70 s/mm^2, the blanks pass the blank contamination test and one may proceed to the Z-test. If the arithmetic mean is greater than 70 s/mm^2, it is likely that the blanks have been contaminated by asbestos structures from a source other than the sampled air. The validity of the inside and outside samples is questionable. They must be discarded and new samples collected.

Before collecting new samples, attempt to identify and eliminate the source of contamination. If asbestos structures are present on the sealed blank, the filters may have been contaminated during manufacture. Select new filters from lots that have been prescreened. (Laboratories are required to screen filters from the lots they use for their internal quality control.) If the majority of asbestos structures are on the field blanks, contamination may have occurred during the field sampling or laboratory analysis. Check field procedures and ask the laboratory for the results of blank analyses that they are required to perform as a part of their laboratory quality control program. During the resampling ensure that the sampling, handling, and analysis protocols are strictly followed to avoid a repeat of the contamination problem.

Example 4. Analysis of three blanks gives the results shown in Figure 5. The arithmetic mean of the three concentrations is less than 70 s/mm^2 and the blanks pass the contamination test. The laboratory proceeds with the analysis of the outside samples.

Example 5. The three blanks in Figure 6 do not pass the blank contamination test. The cause of the failure appears to be the field blank collected inside the work site. The sampling technician recalls that the sampling cassettes were accidentally stored in the work site while the abatement was in progress. A new supply of cassettes is obtained and the entire sampling and analysis procedure is repeated.

BLANK CONTAMINATION TEST

Work Sheet

Blanks

blanks, n_B, = 3

Blank 1 0.00 s/mm^2

Blank 2 17.60 s/mm^2

Blank 3 0.00 s/mm^2

Blank 4 ______ s/mm^2

Blank 5 ______ s/mm^2

Blank 6 ______ s/mm^2

Blank 7 ______ s/mm^2

Blank 8 ______ s/mm^2

. .
. .
. .

Blank n_B ______ s/mm^2

Total 17.60

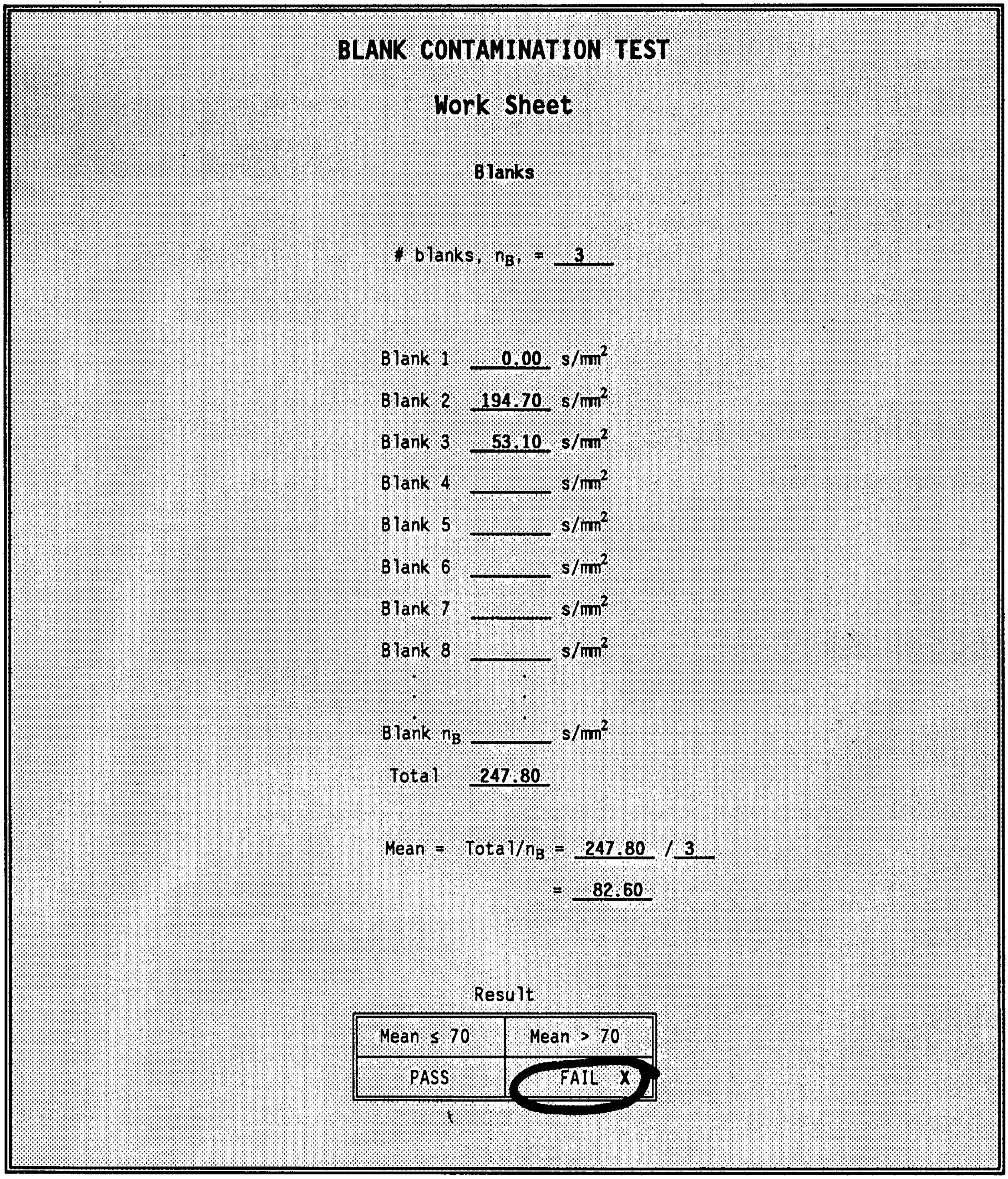
Mean = Total/n_B = 17.60 / 3

= 5.87

Result

Mean ≤ 70	Mean > 70
[✓ PASS X]	FAIL

Figure 5. The Blank Contamination Test -- Example 4. In this example the blanks pass the test and the laboratory proceeds to the analysis of the outside samples.



BLANK CONTAMINATION TEST

Work Sheet

Blanks

blanks, n_B, = 3

Blank 1 0.00 s/mm^2

Blank 2 194.70 s/mm^2

Blank 3 53.10 s/mm^2

Blank 4 ______ s/mm^2

Blank 5 ______ s/mm^2

Blank 6 ______ s/mm^2

Blank 7 ______ s/mm^2

Blank 8 ______ s/mm^2

.
.
.

Blank n_B ______ s/mm^2

Total 247.80

Mean = Total/n_B = 247.80 / 3

= 82.60

Result

Mean ≤ 70	Mean > 70
PASS	[✓ FAIL X]

Figure 6. The Blank Contamination Test -- Example 5. In this example the blanks fail the test. The problem must be corrected and a new set of samples (inside, blank, and outside) collected.

5.3 Z-test

After passing the blank contamination test, the outside samples are analyzed and compared with the inside samples using the Z-test. Note that the Z-test is a comparison of airborne asbestos levels inside and outside the work site and therefore is based on the concentrations per cubic centimeter of air.

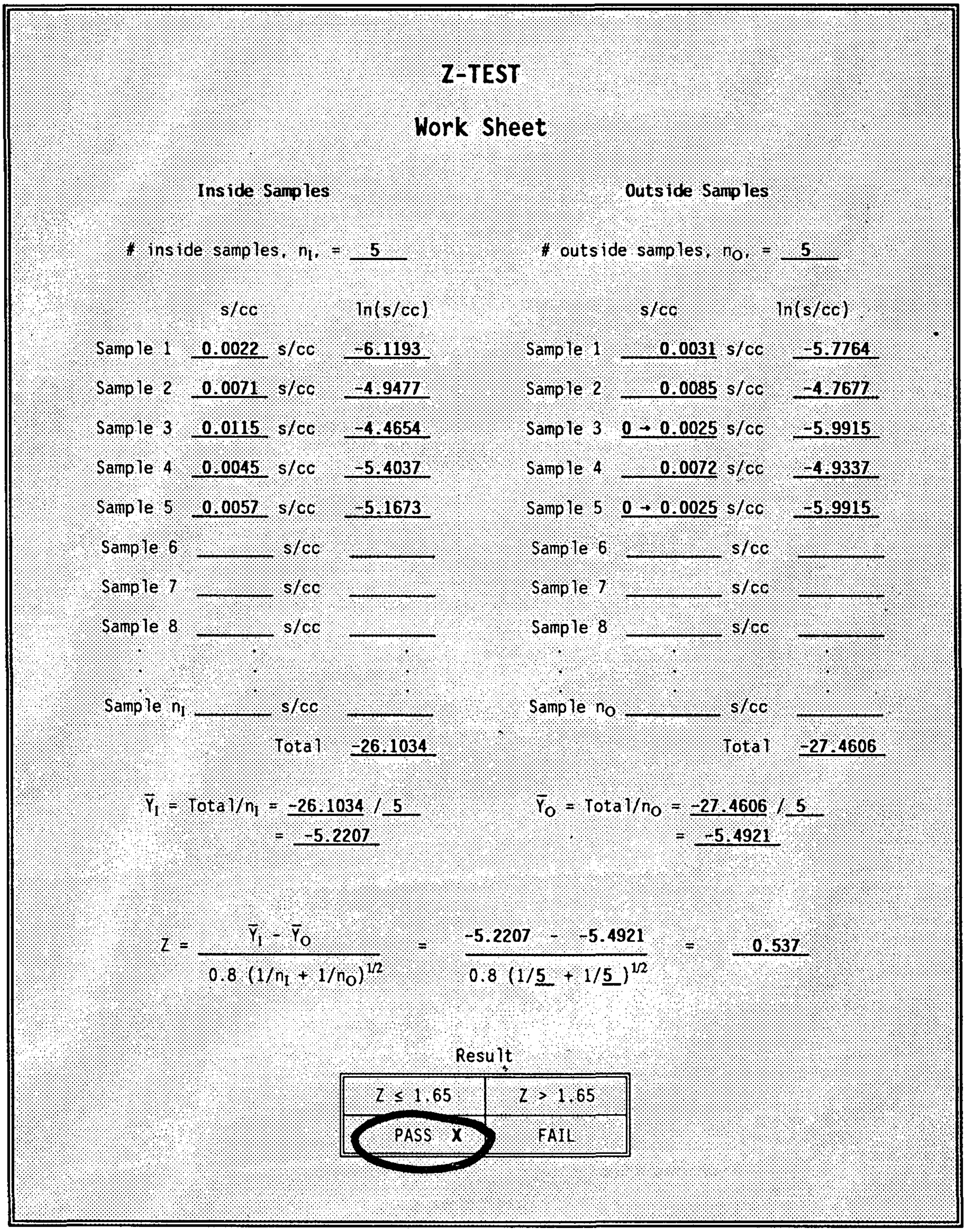
The Z-test uses natural logarithms. Since it is not possible to take the logarithm of zero, samples on which no asbestos structures were detected are given a small positive value. In the AHERA rule this small value is referred to as the "detection limit," although this term is used differently in other contexts. The statement is meant to apply only to the Z-test, not to the initial screening test. In its current form, the wording of the rule is ambiguous. (A clarification is anticipated in an upcoming revision.) In line with the expected revision, it is recommended that 0.0025 s/cc be substituted for any zero concentration prior to taking logarithms. Calculate the arithmetic mean of the logarithms for the inside samples ($\bar{Y}_I$) and the arithmetic mean of the logarithms for outside samples ($\bar{Y}_0$). Then calculate Z according to the formula

$$Z = \frac{\bar{Y}_I - \bar{Y}_0}{0.8\ (1/n_I + 1/n_0)^{1/2}}$$

where n_I is the number of inside samples and n_0 is the number of outside samples. If Z is less than or equal to 1.65, the inside and outside concentrations are not statistically different from each other and the work site passes the clearance test. If Z is greater than 1.65 the work site fails the clearance test. The work site must be recleaned and the sampling and analysis procedures repeated.

Example 6. Figure 7 shows the structure concentrations per cubic centimeter of air for five inside samples and five outside samples. No structures were observed on two of the outside samples. Their concentrations were replaced by 0.0025 before taking logarithms. Z is less than 1.65 and therefore the work site passes the clearance test.

Example 7. In this example the LEA decided to collect and analyze 8 inside samples (one per room) and 5 outside samples. The results are shown in Figure 8. Z is greater than 1.65 and the work site failed the clearance test. The entire work site was recleaned with special emphasis given to the two rooms in which the fifth and seventh samples were collected.



Z-TEST

Work Sheet

Inside Samples				**Outside Samples**			
# inside samples, n_I, = 5				# outside samples, n_O, = 5			
	s/cc		ln(s/cc)		s/cc		ln(s/cc)
Sample 1	0.0022	s/cc	-6.1193	Sample 1	0.0031	s/cc	-5.7764
Sample 2	0.0071	s/cc	-4.9477	Sample 2	0.0085	s/cc	-4.7677
Sample 3	0.0115	s/cc	-4.4654	Sample 3	0 → 0.0025	s/cc	-5.9915
Sample 4	0.0045	s/cc	-5.4037	Sample 4	0.0072	s/cc	-4.9337
Sample 5	0.0057	s/cc	-5.1673	Sample 5	0 → 0.0025	s/cc	-5.9915
Sample 6		s/cc		Sample 6		s/cc	
Sample 7		s/cc		Sample 7		s/cc	
Sample 8		s/cc		Sample 8		s/cc	
⋮	⋮		⋮	⋮	⋮		⋮
Sample n_I		s/cc		Sample n_O		s/cc	
		Total	-26.1034			Total	-27.4606

$\bar{Y}_I$ = Total/n_I = -26.1034 / 5
= -5.2207

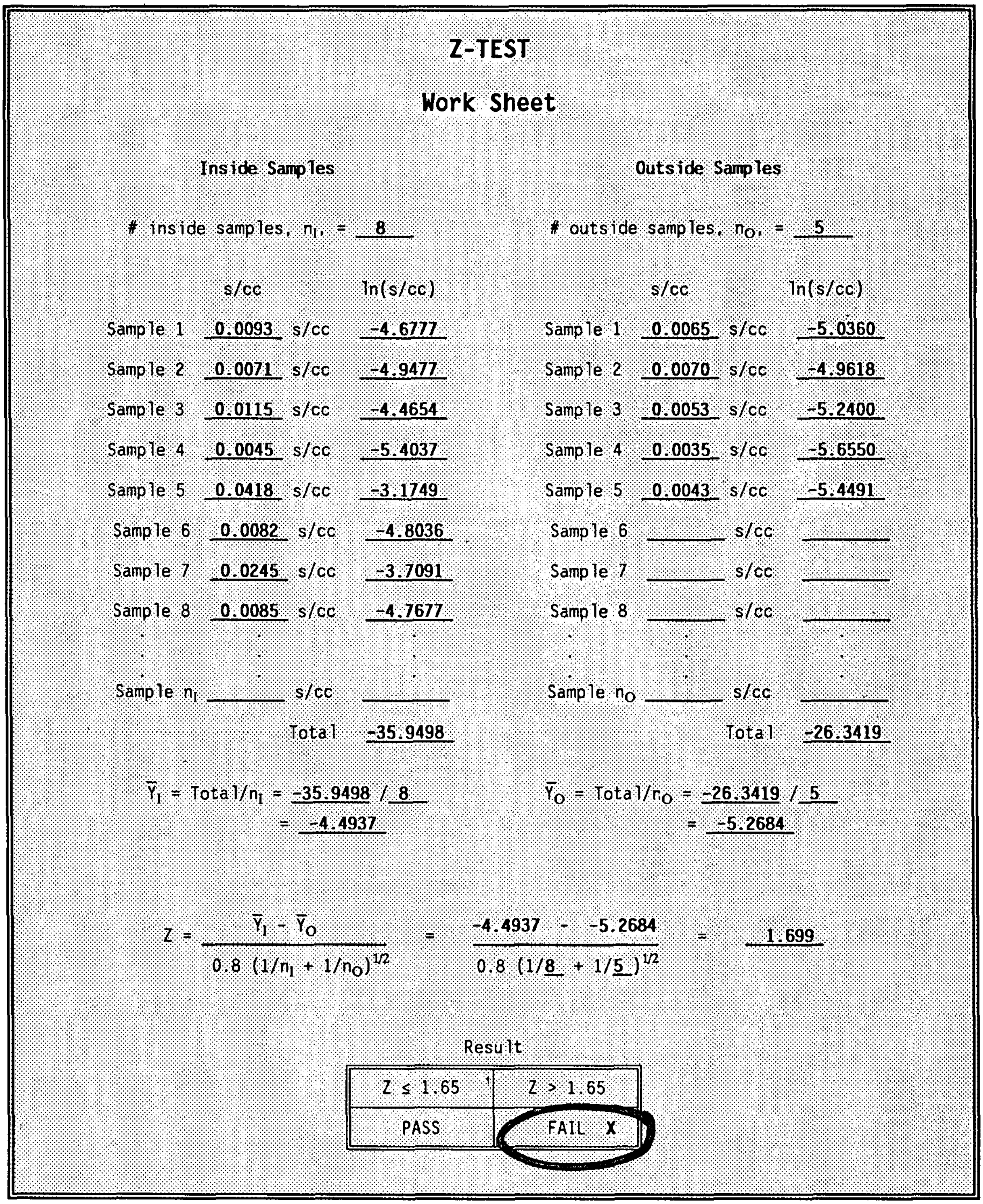
$\bar{Y}_O$ = Total/n_O = -27.4606 / 5
= -5.4921

$$Z = \frac{\bar{Y}_I - \bar{Y}_O}{0.8\ (1/n_I + 1/n_O)^{1/2}} = \frac{-5.2207 \ - \ -5.4921}{0.8\ (1/\underline{5} + 1/\underline{5})^{1/2}} = \underline{0.537}$$

Result

Z ≤ 1.65	Z > 1.65
[✓ PASS X]	FAIL

Figure 7. The Z-test -- Example 6. In this example the work site passes the clearance test.



Z-TEST

Work Sheet

Inside Samples

inside samples, n_I, = 8

	s/cc		ln(s/cc)
Sample 1	0.0093	s/cc	-4.6777
Sample 2	0.0071	s/cc	-4.9477
Sample 3	0.0115	s/cc	-4.4654
Sample 4	0.0045	s/cc	-5.4037
Sample 5	0.0418	s/cc	-3.1749
Sample 6	0.0082	s/cc	-4.8036
Sample 7	0.0245	s/cc	-3.7091
Sample 8	0.0085	s/cc	-4.7677
.	.		.
Sample n_I		s/cc	
		Total	-35.9498

$\bar{Y}_I$ = Total/n_I = -35.9498 / 8
= -4.4937

Outside Samples

outside samples, n_O, = 5

	s/cc		ln(s/cc)
Sample 1	0.0065	s/cc	-5.0360
Sample 2	0.0070	s/cc	-4.9618
Sample 3	0.0053	s/cc	-5.2400
Sample 4	0.0035	s/cc	-5.6550
Sample 5	0.0043	s/cc	-5.4491
Sample 6		s/cc	
Sample 7		s/cc	
Sample 8		s/cc	
.	.		.
Sample n_O		s/cc	
		Total	-26.3419

$\bar{Y}_O$ = Total/n_O = -26.3419 / 5
= -5.2684

$$Z = \frac{\bar{Y}_I - \bar{Y}_O}{0.8\ (1/n_I + 1/n_O)^{1/2}} = \frac{-4.4937\ -\ -5.2684}{0.8\ (1/\underline{8} + 1/\underline{5})^{1/2}} = \underline{1.699}$$

Result

Z ≤ 1.65	Z > 1.65
PASS	[✓ FAIL X]

Figure 8. The Z-test -- Example 7. In this example the work site fails the clearance test. The site must be recleaned and a new set of samples collected.

Example 8. The results shown in Figure 9 give a value of Z that is less than 1.65 and therefore the work site passes the test. However, airborne asbestos levels both inside and outside the work site were somewhat higher than those measured after abatement projects in neighboring schools. The LEA decided that it would be prudent to investigate the matter further and asked its asbestos consultant to investigate and report on other potential sources of asbestos both inside and outside the building. Meanwhile, a special asbestos operations and maintenance program remained in effect throughout the school.

Example 9. The Z-value in this example is greater than 1.65 (Figure 10). Therefore the work site does not pass the clearance test. Examination of the laboratory report revealed that the asbestos structures identified on the inside samples were amosite, while the removal had involved only chrysotile asbestos. After a thorough inspection, previously undetected amosite insulation was discovered on pipes above the suspended ceiling. Minor damage to the pipe insulation was repaired and the work site, including above the ceiling, was recleaned before collecting a new set of air samples.

The preceding examples, as well as demonstrating how to perform the Z-test, indicate that the LEA can and should take into account additional information to decide when an abatement project is complete. Where possible, the contract with the abatement contractor should reflect this to avoid later disagreements. The laboratory report will indicate the type of asbestos (for example, chrysotile or amphibole) and the types of asbestos structures observed (individual fibers or complex structures such as bundles, clusters, or matrices consisting of multiple fibers). The LEA might consider recleaning, if, for example, the work site just passes the Z-test but the inside samples are predominantly amphibole, whereas the outside are exclusively chrysotile. A predominance of complex structures inside the work site compared to single fibers outside the work site, may also suggest that conditions inside the work site are not yet comparable with those outside the work site.

Z-TEST

Work Sheet

Inside Samples				**Outside Samples**			
# inside samples, n_I, = 8				# outside samples, n_O, = 8			
	s/cc		ln(s/cc)		s/cc		ln(s/cc)
Sample 1	0.0093	s/cc	-4.6777	Sample 1	0.0065	s/cc	-5.0360
Sample 2	0.0154	s/cc	-4.1734	Sample 2	0.0154	s/cc	-4.1734
Sample 3	0.0115	s/cc	-4.4654	Sample 3	0.0341	s/cc	-3.3785
Sample 4	0.0245	s/cc	-3.7091	Sample 4	0.0287	s/cc	-3.5509
Sample 5	0.0418	s/cc	-3.1749	Sample 5	0.0043	s/cc	-5.4491
Sample 6	0.0098	s/cc	-4.6254	Sample 6	0.0136	s/cc	-4.2977
Sample 7	0.0162	s/cc	-4.1227	Sample 7	0.0057	s/cc	-5.1673
Sample 8	0.0326	s/cc	-3.4234	Sample 8	0.0223	s/cc	-3.8032
⋮	⋮		⋮	⋮	⋮		⋮
Sample n_I		s/cc		Sample n_O		s/cc	
		Total	-32.3720			Total	-34.8559

$\bar{Y}_I$ = Total/n_I = -32.3720 / 8
= -4.0465

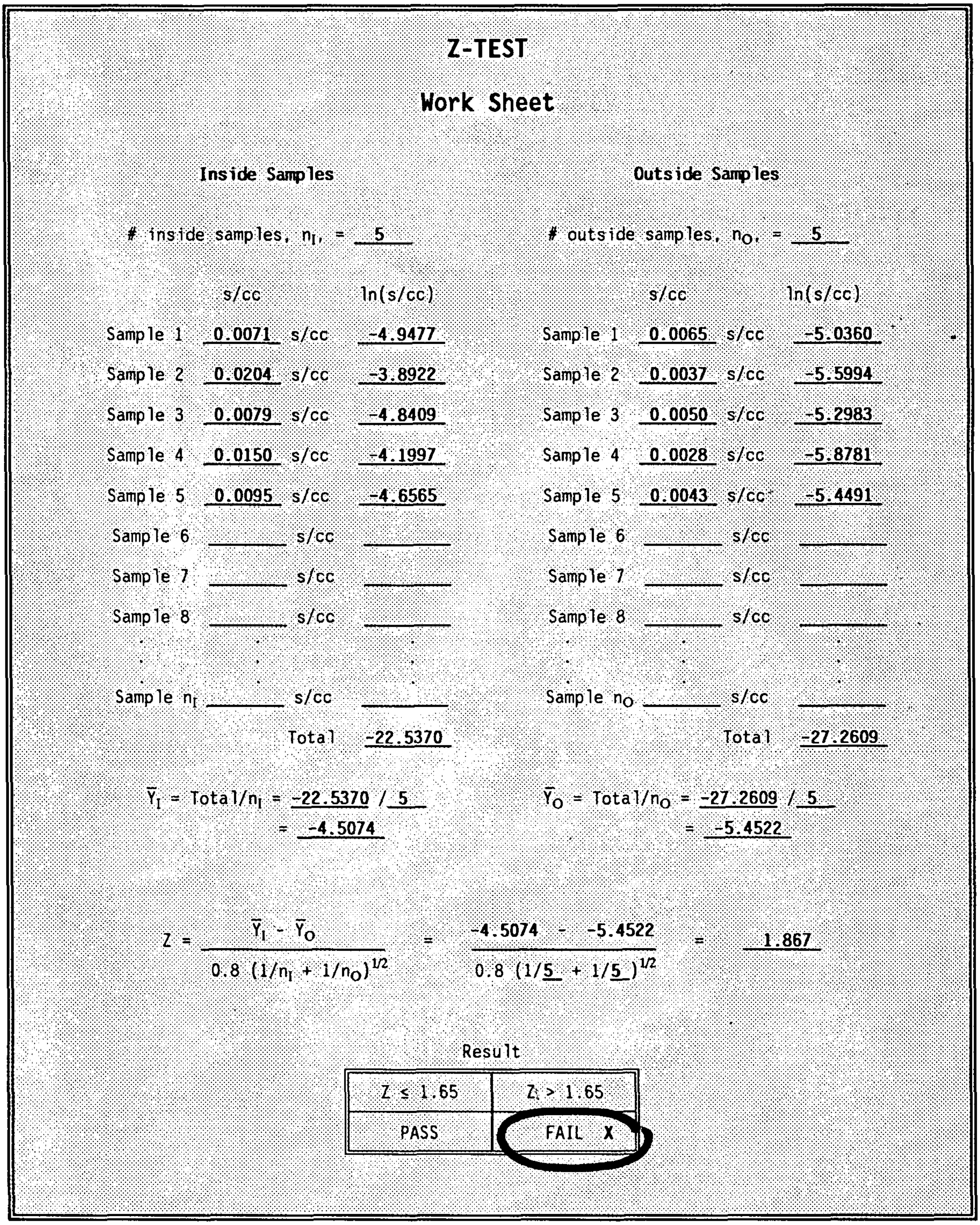
$\bar{Y}_O$ = Total/n_O = -34.8559 / 8
= -4.3570

$$Z = \frac{\bar{Y}_I - \bar{Y}_O}{0.8\ (1/n_I + 1/n_O)^{1/2}} = \frac{-4.0465\ -\ -4.3570}{0.8\ (1/8 + 1/8)^{1/2}} = 0.776$$

Result

Z ≤ 1.65	Z > 1.65
[✓ PASS X]	FAIL

Figure 9. The Z-test -- Example 8. In this example the work site passes the clearance test.



Z-TEST

Work Sheet

Inside Samples				**Outside Samples**			
# inside samples, n_I, = 5				# outside samples, n_O, = 5			
	s/cc		ln(s/cc)		s/cc		ln(s/cc)
Sample 1	0.0071	s/cc	-4.9477	Sample 1	0.0065	s/cc	-5.0360
Sample 2	0.0204	s/cc	-3.8922	Sample 2	0.0037	s/cc	-5.5994
Sample 3	0.0079	s/cc	-4.8409	Sample 3	0.0050	s/cc	-5.2983
Sample 4	0.0150	s/cc	-4.1997	Sample 4	0.0028	s/cc	-5.8781
Sample 5	0.0095	s/cc	-4.6565	Sample 5	0.0043	s/cc	-5.4491
Sample 6		s/cc		Sample 6		s/cc	
Sample 7		s/cc		Sample 7		s/cc	
Sample 8		s/cc		Sample 8		s/cc	
⋮	⋮		⋮	⋮	⋮		⋮
Sample n_I		s/cc		Sample n_O		s/cc	
		Total	-22.5370			Total	-27.2609

$\bar{Y}_I$ = Total/n_I = -22.5370 / 5 = -4.5074

$\bar{Y}_O$ = Total/n_O = -27.2609 / 5 = -5.4522

$$Z = \frac{\bar{Y}_I - \bar{Y}_O}{0.8\ (1/n_I + 1/n_O)^{1/2}} = \frac{-4.5074 \ - \ -5.4522}{0.8\ (1/\underline{5} + 1/\underline{5})^{1/2}} = \underline{1.867}$$

Result

$Z \le 1.65$	$Z > 1.65$
PASS	[✓ FAIL X]

Figure 10. The Z-test -- Example 9. In this example the work site fails the clearance test. The site must be recleaned and new samples collected.

REFERENCES

USEPA. 1985a. U.S. Environmental Protection Agency. Guidance for controlling asbestos-containing materials in buildings. Washington, DC: Office of Toxic Substances, USEPA. EPA 560/5-85-019.

USEPA. 1985b. U.S. Environmental Protection Agency. Measuring airborne asbestos following an abatement action. Research Triangle Park, NC: Environmental Monitoring Systems Laboratory and Office of Toxic Substances, USEPA. EPA 600/4-85-049.

APPENDIX A

WORK SHEETS

Note: Identifying information such as location, sample ID, date, and signature of the evaluator should be added if the work sheets are to be used as permanent documentation.

INITIAL SCREENING TEST

WORK SHEET

Inside Samples

inside samples, n_I, = ______

Sample 1 ________ s/mm^2

Sample 2 ________ s/mm^2

Sample 3 ________ s/mm^2

Sample 4 ________ s/mm^2

Sample 5 ________ s/mm^2

Sample 6 ________ s/mm^2

Sample 7 ________ s/mm^2

Sample 8 ________ s/mm^2

. .

. .

. .

Sample n_I ________ s/mm^2

Total ________

Mean = Total/n_I = ________ /____

= ________

Circle Result

Mean ≤ 70	Mean > 70
PASS	FAIL

BLANK CONTAMINATION TEST

WORK SHEET

Blanks

blanks, n_B, = ______

Blank 1 ________ s/mm^2

Blank 2 ________ s/mm^2

Blank 3 ________ s/mm^2

Blank 4 ________ s/mm^2

Blank 5 ________ s/mm^2

Blank 6 ________ s/mm^2

Blank 7 ________ s/mm^2

Blank 8 ________ s/mm^2

. .
. .
. .

Blank n_B ________ s/mm^2

Total ________

Mean = Total/n_B = ________ /____

= ________

Circle Result

Mean ≤ 70	Mean > 70
PASS	FAIL

Z-TEST

WORK SHEET

Inside Samples

inside samples, n_I, = ______

s/cc ln(s/cc)

Sample 1 ________ s/cc ________
Sample 2 ________ s/cc ________
Sample 3 ________ s/cc ________
Sample 4 ________ s/cc ________
Sample 5 ________ s/cc ________
Sample 6 ________ s/cc ________
Sample 7 ________ s/cc ________
Sample 8 ________ s/cc ________
⋮
Sample n_I ________ s/cc ________
Total ________

$\overline{Y}_I$ = Total/n_I = ________ /____
= ________

Outside Samples

outside samples, n_O, = ______

s/cc ln(s/cc)

Sample 1 ________ s/cc ________
Sample 2 ________ s/cc ________
Sample 3 ________ s/cc ________
Sample 4 ________ s/cc ________
Sample 5 ________ s/cc ________
Sample 6 ________ s/cc ________
Sample 7 ________ s/cc ________
Sample 8 ________ s/cc ________
⋮
Sample n_O ________ s/cc ________
Total ________

$\overline{Y}_O$ = Total/n_O = ________ /____
= ________

$$Z = \frac{\overline{Y}_I - \overline{Y}_O}{0.8\ (1/n_I + 1/n_O)^{1/2}} = \frac{\_\_\_\_ - \_\_\_\_}{0.8\ (1/\_\_ + 1/\_\_)^{1/2}} = \_\_\_\_\_\_\_\_$$

Circle Result

$Z \leq 1.65$	$Z > 1.65$
PASS	FAIL

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16. Abstract (Limit: 200 words)

Guidance is provided for conducting the transmission electron microscopy clearance test required under the Asbestos Hazard Emergency Response Act (40 CFR Part 763) to determine when an asbestos abatement site is sufficiently clean for the containment barriers to be removed. Emphasis is on interpretation of the results. The three components of the clearance test -- the initial screening test, the blank contamination test, and the Z-test -- are described and illustrated with numerical examples.

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AHERA, asbestos, asbestos air monitoring, asbestos abatement, clearance, TEM, transmission electron microscopy.

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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