



Test Method

Interim Method for the Determination of Asbestos in Bulk Insulation Samples*

1. Polarized Light Microscopy

1.1 Principle and Applicability

Bulk samples of building materials taken for asbestos identification are first examined for homogeneity and preliminary fiber identification at low magnification. Positive identification of suspect fibers is made by analysis of subsamples with the polarized light microscope.

The principles of optical mineralogy are well established.^{1,2} A light microscope equipped with two polarizing filters is used to observe specific optical characteristics of a sample. The use of plane polarized-light allows the determination of refractive indices along specific crystallographic axes. Morphology and color are also observed. A retardation plate is placed in the polarized light path for determination of the sign of elongation using orthoscopic illumination. Orientation of the two filters such that their vibration planes are perpendicular (crossed polars) allows observation of the birefringence and extinction characteristics of anisotropic particles.

Quantitative analysis involves the use of point counting. Point counting is a standard technique in petrography for determining the relative areas occupied by separate minerals in thin sections of rock. Background information on the use of point counting³ and the interpretation of point count data³ is available.

*An interim method is carefully drafted from available source information. This method is still under investigation and therefore is subject to revision.

This method is applicable to all bulk samples of friable insulation materials submitted for identification and quantitation of asbestos components.

1.2 Range

The point counting method may be used for analysis of samples containing from 0 to 100 percent asbestos. The upper detection limit is 100 percent. The lower detection limit is less than 1 percent.

1.3 Interferences

Fibrous organic and inorganic constituents of bulk samples may interfere with the identification and quantitation of the asbestos mineral content. Spray-on binder materials may coat fibers and affect color or obscure optical characteristics to the extent of masking fiber identity. Fine particles of other materials may also adhere to fibers to an extent sufficient to cause confusion in identification. Procedures that may be used for the removal of interferences are presented in Section 1.7.2.2.

1.4 Precision and Accuracy

Adequate data for measuring the accuracy and precision of the method for samples with various matrices are not currently available. Data obtained for samples containing a single asbestos type in a simple matrix are available in the EPA report *Bulk Sample Analysis for Asbestos Content: Evaluation of the Tentative Method*.⁴

1.5 Apparatus

1.5.1 Sample Analysis

A low-power binocular microscope, preferably stereoscopic, is used to

examine the bulk insulation sample as received.

- **Microscope:** binocular, 10-45X (approximate)
- **Light Source:** incandescent or fluorescent
- **Forceps, Dissecting Needles, and Probes**
- **Glassine Paper or Clean Glass Plate**

Compound microscope requirements: A polarized light microscope complete with polarizer, analyzer, port for wave retardation plate, 360° graduated rotating stage, substage condenser, lamp, and lamp iris.

- **Polarized Light Microscope:** described above
- **Objective Lenses:** 10X, 20X, and 40X or near equivalent
- **Dispersion Staining Objective Lens** (optional)
- **Ocular Lens:** 10X minimum
- **Eyepiece Reticle:** cross hair or 25 point Chalkley Point Array
- **Compensator Plate:** 550 milli-micron retardation

1.5.2 Sample Preparation

Sample preparation apparatus requirements will depend upon the type of insulation sample under consideration. Various physical and/or chemical means may be employed for an adequate sample assessment.

- **Ventilated Hood** or negative pressure glove box
- **Microscope Slides**
- **Coverslips**
- **Mortar and Pestle:** agate or porcelain (optional)
- **Wiley Mill** (optional)
- **Beakers & assorted glassware** (optional)
- **Centrifuge** (optional)
- **Filtration apparatus** (optional)
- **Low temperature asher** (optional)

1.6 Reagents

1.6.1 Sample Preparation

- **Distilled Water** (optional)
- **Dilute CH_3COOH :** ACS reagent grade (optional)
- **Dilute HCl :** ACS reagent grade (optional)
- **Sodium metaphosphate (NaPO_3)_n** (optional)

1.6.2 Analytical Reagents

- **Refractive Index Liquids:** 1.490-1.570, 1.590-1.720 in increments of 0.002 or 0.004
- **Refractive Index Liquids for Dispersion Staining:** high-dispersion series, 1.550, 1.605, 1.630 (optional)
- **UICC Asbestos Reference Sample Set:** Available from: UICC MRC

Pneumoconiosis Unit, Llandough Hospital, Penarth, Glamorgan CF6 1XW, UK, and commercial distributors

- **Tremolite-asbestos** (source to be determined)
- **Actinolite-asbestos** (source to be determined)

1.7 Procedures

Note: Exposure to airborne asbestos fibers is a health hazard. Bulk samples submitted for analysis are usually friable and may release fibers during handling or matrix reduction steps. All sample and slide preparations should be carried out in a ventilated hood or glove box with continuous airflow (negative pressure). Handling of samples without these precautions may result in exposure of the analyst and contamination of samples by airborne fibers.

1.7.1 Sampling

Samples for analysis of asbestos content shall be taken in the manner prescribed in Reference 5 and information on design of sampling and analysis programs may be found in Reference 6. If there are any questions about the representative nature of the sample, another sample should be requested before proceeding with the analysis.

1.7.2 Analysis

1.7.2.1 Gross Examination

Bulk samples of building materials taken for the identification and quantitation of asbestos are first examined for homogeneity at low magnification with the aid of a stereomicroscope. The core sample may be examined in its container or carefully removed from the container onto a glassine transfer paper or clean glass plate. If possible, note is made of the orientation of top and bottom surfaces. When discrete strata are identified, each is treated as a separate material so that fibers are first identified and quantified in that layer only, and then the results for each layer are combined to yield an estimate of asbestos content for the whole sample.

1.7.2.2 Sample Preparation

Bulk materials submitted for asbestos analysis involve a wide variety of matrix materials. Representative subsamples may not be readily obtainable by simple means in heterogeneous materials, and various steps may be required to alleviate the difficulties encountered. In most cases, however, the best preparation is made by using forceps to sample at several places from the bulk material. Forcep samples are immersed in a refractive index liquid on a microscope slide,

leaved apart, covered with a glass, and observed with the polarized light microscope.

Alternatively, attempts may be made to homogenize the sample or eliminate interferences before further characterization. The selection of appropriate procedures is dependent upon the samples encountered and personal preference. The following are presented as possible sample preparation steps.

A mortar and pestle can sometimes be used in the size reduction of soft or loosely bound materials, though this may cause matting of some samples. Such samples may be reduced in a Wiley mill. Apparatus should be clean and extreme care exercised to avoid cross-contamination of samples. Periodic checks of the particle sizes should be made during the grinding operation so as to preserve any fiber bundles present in an identifiable form. These procedures are not recommended for samples that contain amphibole minerals or vermiculite. Grinding of amphiboles may result in the separation of fiber bundles or the production of cleavage fragments that have aspect ratios greater than 3:1 and will be classified as asbestos fibers. Grinding of vermiculite may also produce fragments with aspect ratios greater than 3:1.

Acid treatment may occasionally be required to eliminate interferences. Calcium carbonate, gypsum, and bassanite (plaster) are frequently present in sprayed or trowelled insulations. These materials may be removed by treatment with warm dilute acetic acid. Warm dilute hydrochloric acid may also be used to remove the above materials. If acid treatment is required, wash the sample at least twice with distilled water, being careful not to lose the particulates during decanting steps. Centrifugation or filtration of the suspension will prevent significant fiber loss. The pore size of the filter should be 0.45 micron or less. *Caution: prolonged acid contact with the sample may alter the optical characteristics of chrysotile fibers and should be avoided.*

Coatings and binding materials adhering to fiber surfaces may also be removed by treatment with sodium metaphosphate.⁷ Add 10 mL of 10 g/L sodium metaphosphate solution to a small (0.1 to 0.5 mL) sample of bulk material in a 15-mL glass centrifuge tube. For approximately 15 seconds each, stir the mixture on a vortex mixer, place in an ultrasonic bath and then shake by hand. Repeat the series.

Collect the dispersed solids by centrifugation at 1000 rpm for 5 minutes. Wash the sample three times by suspending in 10 mL distilled water and recentrifuging. After washing, resuspend the pellet in 5 mL distilled water, place a drop of the suspension on a microscope slide, and dry the slide at 110°C.

In samples with a large portion of cellulosic or other organic fibers, it may be useful to ash part of the sample and examine the residue. Ashing should be performed in a low temperature ashers. Ashing may also be performed in a muffle furnace at temperatures of 500°C or lower. Temperatures of 550°C or higher will cause dehydroxylation of the asbestos minerals, resulting in changes of the refractive index and other key parameters. If a muffle furnace is to be used, the furnace thermostat should be checked and calibrated to ensure that samples will not be heated at temperatures greater than 500°C.

Ashing and acid treatment of samples should not be used as standard procedures. In order to monitor possible changes in fiber characteristics, the material should be viewed microscopically before and after any sample preparation procedure. Use of these procedures on samples to be used for quantitation requires a correction for percent weight loss.

1.7.2.3 Fiber Identification

Positive identification of asbestos requires the determination of the following optical properties.

- Morphology
- Color and pleochroism
- Refractive indices
- Birefringence
- Extinction characteristics
- Sign of elongation

Table 1-1 lists the above properties for commercial asbestos fibers. Figure 1-1 presents a flow diagram of the examination procedure. Natural variations in the conditions under which deposits of asbestiform minerals are formed will produce exceptions to the published values and differences from the UICC standards. The sign of elongation is determined by use of the compensator plate and crossed polars. Refractive indices may be determined by the Becke line test. Alternatively, dispersion staining may be used. Inexperienced operators may find that the dispersion staining technique is more easily learned, and should consult Reference 9 for guidance. Central stop dispersion staining colors are presented in Table

1-2. Available high-dispersion (HD) liquids should be used.

1.7.2.4 Quantitation of Asbestos Content

Asbestos quantitation is performed by a point-counting procedure. An ocular reticle (cross-hair or point array) is used to visually superimpose a point or points on the microscope field of view. Record the number of points positioned directly above each kind of particle or fiber of interest. Score only points directly over asbestos fibers or nonasbestos matrix material. Do not score empty points for the closest particle. If an asbestos fiber and a matrix particle overlap so that a point is superimposed on their visual intersection, a point is scored for both categories. Point counting provides a determination of the area percent asbestos. Reliable conversion of area percent to percent of dry weight is not currently feasible unless the specific gravities and relative volumes of the materials are known.

For the purpose of this method, "asbestos fibers" are defined as having an aspect ratio greater than 3:1 and being positively identified as one of the minerals in Table 1-1.

A total of 400 points superimposed on either asbestos fibers or nonasbestos matrix material must be counted over at least eight different preparations of representative subsamples. Take eight forcep samples and mount each separately with the appropriate refractive index liquid. The preparation should not be heavily loaded. The sample should be uniformly dispersed to avoid overlapping particles and allow 25-50 percent empty area within the fields of view. Count 50 nonempty points on each preparation, using either

- A cross-hair reticle and mechanical stage; or
- A reticle with 25 points (Chalkley Point Array) and counting at least 2 randomly selected fields.

For samples with mixtures of isotropic and anisotropic materials present, viewing the sample with slightly uncrossed polars or the addition of the compensator plate to the plane polarized light path will allow simultaneous discrimination of both particle types. Quantitation should be performed at 100X or at the lowest magnification of the polarized light microscope that can effectively distinguish the sample components. Confirmation of the quantitation result by a second analyst on some percentage of analyzed samples should be used as standard quality control procedure.

The percent asbestos is calculated as follows:

$$\% \text{ asbestos} = (a/n) 100\%$$

where

a = number of asbestos counts,
n = number of nonempty points counted (400).

If a = 0, report "No asbestos detected." If $0 < a \leq 3$, report "<1% asbestos."

The value reported should be rounded to the nearest percent.

1.8 References

1. Paul F. Kerr, *Optical Mineralogy*, 4th ed., New York, McGraw-Hill, 1977.
2. E. M. Chamot and C. W. Mason, *Handbook of Chemical Microscopy, Volume One*, 3rd ed., New York: John Wiley & Sons, 1958.
3. F. Chayes, *Petrographic Modal Analysis: An Elementary Statistical Appraisal*, New York: John Wiley & Sons, 1956.
4. E. P. Brantly, Jr., K. W. Gold, L. E. Myers, and D. E. Lentzen, *Bulk Sample Analysis for Asbestos Content: Evaluation of the Tentative Method*, EPA-600/4-82-021, U.S. Environmental Protection Agency, in preparation.
5. U.S. Environmental Protection Agency, *Asbestos-Containing Materials in School Buildings: A Guidance Document, Parts 1 and 2*, EPA/OTS No. C00090, March 1979.
6. D. Lucas, T. Hartwell, and A. V. Rao, *Asbestos-Containing Materials in School Buildings: Guidance for Asbestos Analytical Programs*, EPA-560/13-80-017A, U.S. Environmental Protection Agency, December 1980.
7. D. H. Taylor and J. S. Bloom, Hexametaphosphate pretreatment of insulation samples for identification of fibrous constituents, *Microscope*, 28, 1980.
8. W. J. Campbell, R. L. Blake, L. L. Brown, E. E. Cather, and J. J. Sjöberg, *Selected Silicate Minerals and Their Asbestiform Varieties: Mineralogical Definitions and Identification-Characterization*, U.S. Bureau of Mines Information Circular 8751, 1977.
9. Walter C. McCrone, *Asbestos Particle Atlas*, Ann Arbor: Ann Arbor Science Publishers, June 1980.

Table 1-1. Optical properties of asbestos fibers

Mineral	Morphology, color ¹	Refractive indices ² α	γ	Birefringence	Extinction	Sign of elongation
Chrysotile (asbestiform serpentine)	Wavy fibers. Fiber bundles have splayed ends and "kinks". Aspect ratio typically >10:1. Colorless ³ , nonpleochroic.	1.493-1.560	1.517-1.562 ⁴ (normally 1.556)	.002-.014	to fiber length	+ (length slow)
Amosite (asbestiform grunerite)	Straight, rigid fibers. Aspect ratio typically >10:1. Colorless to brown, nonpleochroic or weakly so. Opaque inclusions may be present.	1.635-1.696	1.655-1.729 ⁴ (normally 1.696-1.710)	.020-.033	to fiber length	+ (length slow)
Crocidolite (asbestiform riebeckite)	Straight, rigid fibers. Thick fibers and bundles common, blue to purple-blue in color. Pleochroic. Birefringence is generally masked by blue color.	1.654-1.701	1.668-1.717 ⁴ (normally close to 1.700)	.014-.016	to fiber length	- (length fast)
Anthrophyllite-asbestos	Straight, single fibers, some larger composite fibers. Anthrophyllite cleavage fragments may be present with aspect ratios < 10:1. ⁴ Colorless to light brown.	1.596-1.652	1.615-1.676 ⁴	.019-.024	to fiber length	+ (length slow)
Tremolite-actinolite-asbestos	Tremolite-asbestos may be present as single or composite fibers. Tremolite cleavage fragments may be present as single crystals with aspect ratios < 10:1. ⁴ Colorless to pale green.	1.599-1.668	1.622-1.688 ⁴	.023-.020	Oblique extinction, 10-20° for fragments. Composite fibers show extinction.	+ (length slow)

¹ From reference 5; colors cited are seen by observation with plane polarized light. ⁴ Fibers defined as having aspect ratio >3:1.

² From references 5 and 8.

³ Fibers subjected to heating may be brownish.

⁵ $\perp$ to fiber length.

⁶ || to fiber length.

Table 1-2. Central stop dispersion staining colors ^a

Mineral	RI Liquid	$\perp$	
Chrysotile	1.550 nd	Blue	Blue-magenta
"Amosite"	1.580	Blue-magenta to pale blue	Golden-yellow
	1.550 nd	Yellow to white	Yellow to white
Crocidolite ^b	1.700	Red magenta	Blue-magenta
	1.550 nd	Yellow to white	Yellow to white
Anthrophyllite-asbestos	1.605 nd	Blue	Gold to gold-magenta
Tremolite-asbestos	1.605 nd	Pale blue	Yellow
Actinolite-asbestos	1.605 nd	Gold-magenta to blue	Gold
	1.630 nd	Magenta	Golden-yellow

^aFrom reference 9, colors may vary slightly.

^bBlue absorption color.

^cOblique extinction view.

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Polarized light microscopy qualitative analysis: For each type of material identified by examination of sample at low magnification. Mount specially dispersed sample in 1.550 RI liquid. (If using dispersion staining, mount in 1.550 HD.) View at 100X with both plane polarized light and crossed polars. More than one fiber type may be present.

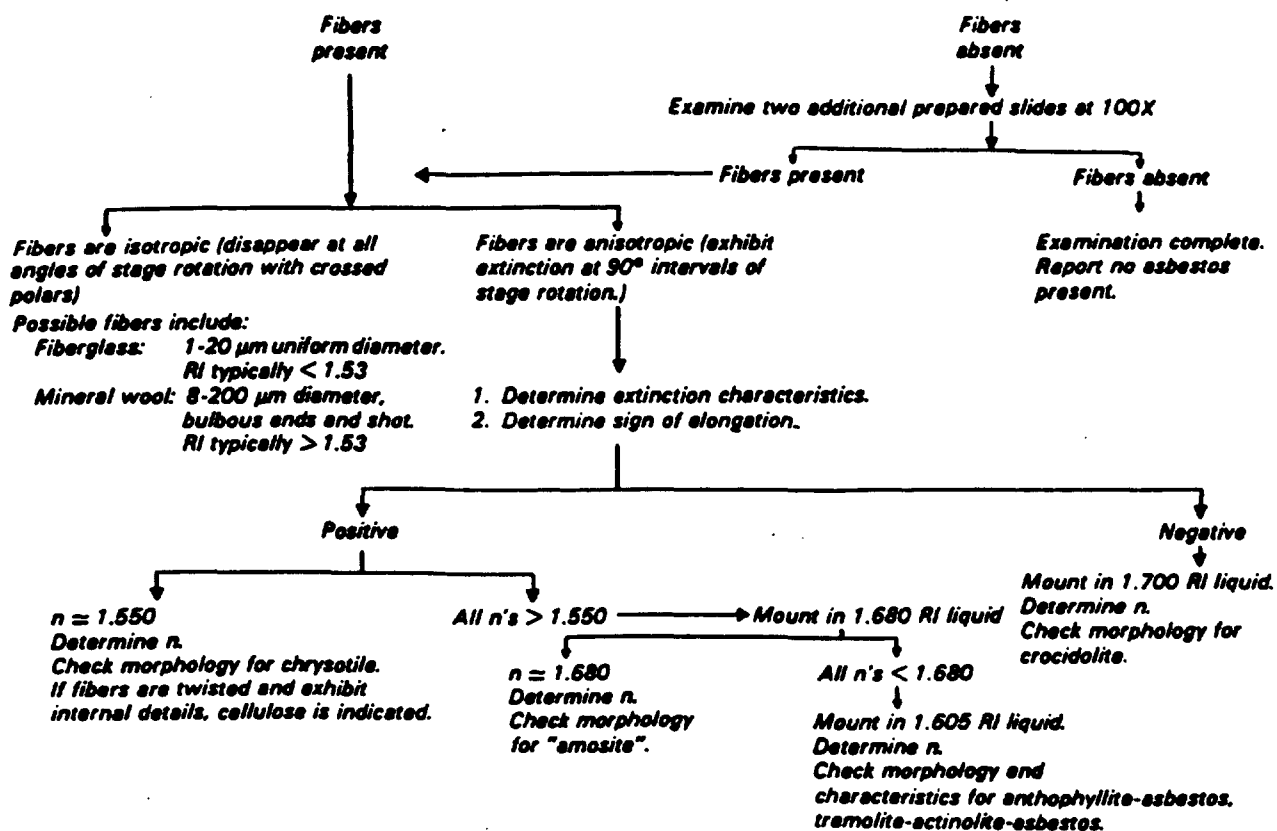


Figure 1-1. Flow chart for qualitative analysis of bulk samples by polarized light microscopy.

2. X-Ray Powder Diffraction

2.1 Principle and Applicability

The principle of X-ray powder diffraction (XRD) analysis is well established.^{1,2} Any solid, crystalline material will diffract an impinging beam of parallel, monochromatic X-rays whenever Bragg's Law,

$$\lambda = 2d \sin \theta,$$

is satisfied for a particular set of planes in the crystal lattice, where

- λ = the X-ray wavelength, Å;
- d = the interplanar spacings of the set of reflecting lattice planes, Å; and
- θ = the angle of incidence between the X-ray beam and the reflecting lattice planes.

By appropriate orientation of a sample relative to the incident X-ray beam, a diffraction pattern can be generated that, in most cases, will be uniquely characteristic of both the chemical composition and structure of the crystalline phases present.

Unlike optical methods of analysis, however, XRD cannot determine crystal morphology. Therefore, in asbestos analysis, XRD does not distinguish between fibrous and nonfibrous forms of the serpentine and amphibole minerals (Table 2-1). However, when used in conjunction with optical methods such as polarized light microscopy (PLM), XRD techniques can provide a reliable analytical method for the identification and characterization of asbestiform minerals in bulk materials.

For *qualitative analysis* by XRD methods, samples are initially scanned over limited diagnostic peak regions for the serpentine (~7.4 Å) and amphibole (8.2-8.5 Å) minerals (Table 2-2). Standard slow-scanning methods for bulk sample analysis may be used for materials shown by PLM to contain significant amounts of asbestos (>5-10 percent). Detection of minor or trace amounts of asbestos may require special sample preparation and step-scanning analysis. All samples that exhibit diffraction peaks in the diagnostic regions for asbestiform minerals are submitted to a full (5°-60° 2 θ ; 1° 2 θ /min) qualitative XRD scan, and their diffraction patterns are compared with standard reference powder diffraction patterns³ to verify initial peak assignments and to identify possible matrix interferences when

subsequent quantitative analysis will be performed.

Accurate *quantitative analysis* of asbestos in bulk samples by XRD is critically dependent on particle size distribution, crystallite size, preferred orientation and matrix absorption effects, and comparability of standard reference and sample materials. The most intense diffraction peak that has been shown to be free from interference by prior qualitative XRD analysis is selected for quantitation of each asbestiform mineral. A "thin-layer" method of analysis^{4,5} is recommended in which, subsequent to comminution of the bulk material to ~10 μ m by suitable cryogenic milling techniques, an accurately known amount of the sample is deposited on a silver membrane filter. The mass of asbestiform material is determined by measuring the integrated area of the selected diffraction peak using a step-scanning mode, correcting for matrix absorption effects, and comparing with suitable calibration standards. Alternative "thick-layer" or bulk methods,^{7,8} may be used for *semiquantitative analysis*.

This XRD method is applicable as a confirmatory method for identification and quantitation of asbestos in bulk material samples that have undergone prior analysis by PLM or other optical methods.

2.2 Range and Sensitivity

The range of the method has not been determined.

The sensitivity of the method has not been determined. It will be variable and dependent upon many factors, including matrix effects (absorption and interferences), diagnostic reflections selected, and their relative intensities.

2.3 Limitations

2.3.1 Interferences

Since the fibrous and nonfibrous forms of the serpentine and amphibole minerals (Table 2-1) are indistinguishable by XRD techniques unless special sample preparation techniques and instrumentation are used,⁹ the presence of nonasbestiform serpentines and amphiboles in a sample will pose severe interference problems in the identification and quantitative analysis of their asbestiform analog

The use of XRD for identification and quantitation of asbestiform minerals in bulk samples may also be limited by the presence of other interfering materials in the sample. For naturally occurring materials the commonly associated asbestos-related mineral interferences can usually be anticipated. However, for fabricated materials the nature of the interferences may vary greatly (Table 2-3) and present more serious problems in identification and quantitation.¹⁰ Potential interferences are summarized in Table 2-4 and include the following:

- *Chlorite* has major peaks at 7.19 Å and 3.58 Å that interfere with both the primary (7.36 Å) and secondary (3.66 Å) peaks for chrysotile. Resolution of the primary peak to give good quantitative results may be possible when a step-scanning mode of operation is employed.
- *Halloysite* has a peak at 3.63 Å that interferes with the secondary (3.66 Å) peak for chrysotile.
- *Kaolinite* has a major peak at 7.15 Å that may interfere with the primary peak of chrysotile at 7.36 Å when present at concentrations of >10 percent. However, the secondary chrysotile peak at 3.66 Å may be used for quantitation.
- *Gypsum* has a major peak at 7.5 Å that overlaps the 7.36 Å peak of chrysotile when present as a major sample constituent. This may be removed by careful washing with distilled water, or by heating to 300°C to convert gypsum to plaster of paris.
- *Cellulose* has a broad peak that partially overlaps the secondary (3.66 Å) chrysotile peak.⁸
- Overlap of major diagnostic peaks of the amphibole asbestos minerals, amosite, anthophyllite, crocidolite, and tremolite, at approximately 8.3 Å and 3.1 Å causes mutual interference when these minerals occur in the presence of one another. In some instances adequate resolution may be attained by using step-scanning methods and/or by decreasing the collimator slit width at the X-ray port.
- *Carbonates* may also interfere with quantitative analysis of the amphibole asbestos minerals, amosite,

anthophyllite, crocidolite, and tremolite. Calcium carbonate (CaCO_3) has a peak at 3.035 Å that overlaps major amphibole peaks at approximately 3.1 Å when present in concentrations of >5 percent. Removal of carbonates with a dilute acid wash is possible; however, if present, chrysotile may be partially dissolved by this treatment.¹¹

- A major talc peak at 3.12 Å interferes with the primary tremolite peak at this same position and with secondary peaks of crocidolite (3.10 Å), amosite (3.06 Å), and anthophyllite (3.05 Å). In the presence of talc, the major diagnostic peak at approximately 8.3 Å should be used for quantitation of these asbestiform minerals.

The problem of intraspecies and matrix interferences is further aggravated by the variability of the silicate mineral powder diffraction patterns themselves, which often makes definitive identification of the asbestos minerals by comparison with standard reference diffraction patterns difficult. This variability results from alterations in the crystal lattice associated with differences in isomorphous substitution and degree of crystallinity. This is especially true for the amphiboles. These minerals exhibit a wide variety of very similar chemical compositions, with the result being that their diffraction patterns are characterized by having major (110) reflections of the monoclinic amphiboles and (210) reflections of the orthorhombic anthophyllite separated by less than 0.2 Å.¹²

2.3.2 Matrix Effects

If a copper X-ray source is used, the presence of iron at high concentrations in a sample will result in significant X-ray fluorescence, leading to loss of peak intensity with increased background intensity and an overall decrease in sensitivity. This situation may be corrected by use of an X-ray source other than copper; however, this is often accompanied both by loss of intensity and by decreased resolution of closely spaced reflections. Alternatively, use of a diffracted beam monochromator will reduce background fluorescent radiation, enabling weaker diffraction peaks to be detected.

X-ray absorption by the sample matrix will result in overall attenuation of the diffracted beam and may seriously interfere with quantitative analysis. Absorption effects may be

minimized by using sufficiently "thin" samples for analysis.^{8,12,14} However, unless absorption effects are known to be the same for both samples and standards, appropriate corrections should be made by referencing diagnostic peak areas to an internal standard^{7,8} or filter substrate (Ag) peak.¹⁴

2.3.3 Particle Size Dependence

Because the intensity of diffracted X-radiation is particle-size dependent, it is essential for accurate quantitative analysis that both sample and standard reference materials have similar particle size distributions. The optimum particle size (i.e., fiber length) range for quantitative analysis of asbestos by XRD has been reported to be 1 to 10 µm.¹⁵ Comparability of sample and standard reference material particle size distributions should be verified by optical microscopy (or another suitable method) prior to analysis.

2.3.4 Preferred Orientation Effects

Preferred orientation of asbestiform minerals during sample preparation often poses a serious problem in quantitative analysis by XRD. A number of techniques have been developed for reducing preferred orientation effects in "thick layer" samples.^{7A,16} For "thin" samples on membrane filters, the preferred orientation effects seem to be both reproducible and favorable to enhancement of the principal diagnostic reflections of asbestos minerals, actually increasing the overall sensitivity of the method.^{12,14} However, further investigation into preferred orientation effects in both thin layer and bulk samples is required.

2.3.5 Lack of Suitably

Characterized Standard Materials

The problem of obtaining and characterizing suitable reference materials for asbestos analysis is clearly recognized. NIOSH has recently directed a major research effort toward the preparation and characterization of analytical reference materials, including asbestos standards;^{14,17} however, these are not available in large quantities for routine analysis.

In addition, the problem of ensuring the comparability of standard reference and sample materials, particularly regarding crystallite size, particle size distribution, and degree of crystallinity, has yet to be adequately addressed. For example, Langer et al.¹⁸ have observed that in insulating matrices, chrysotile tends to break open into bundles more frequently than amphiboles. This results in a line-broadening effect with a resultant

decrease in sensitivity. Unless this effect is the same for both standard and sample materials, the amount of chrysotile in the sample will be underestimated by XRD analysis. To minimize this problem, it is recommended that standardized matrix reduction procedures be used for both sample and standard materials.

2.4 Precision and Accuracy

Precision of the method has not been determined.

Accuracy of the method has not been determined.

2.5 Apparatus

2.5.1 Sample Preparation

Sample preparation apparatus requirements will depend upon the sample type under consideration and the kind of XRD analysis to be performed.

- **Mortar and Pestle:** Agate or porcelain
- **Razor Blades**
- **Sample Mill:** SPEX, Inc., freezer mill or equivalent
- **Bulk Sample Holders**
- **Silver Membrane Filters:** 25-mm diameter, 0.45-µm pore size. Selas Corp. of America, Flotronics Div., 1957 Pioneer Road, Huntingdon Valley, PA 19006
- **Microscope Slides**
- **Vacuum Filtration Apparatus:** Galman No. 1107 or equivalent, and side-arm vacuum flask
- **Microbalance**
- **Ultrasonic Bath or Probe:** Model W140, Ultrasonics, Inc., operated at a power density of approximately 0.1 W/mL or equivalent
- **Volumetric Flasks:** 1-L volume
- **Assorted Pipet**
- **Pipet Bulb**
- **Nonserrated Forceps**
- **Polyethylene Wash Bottle**
- **Pyrex Beakers:** 50-mL volume
- **Desiccator**
- **Filter Storage Cassettes**
- **Magnetic Stirring Plates and Bars**
- **Porcelain Crucibles**
- **Muffle Furnace or Low Temperature Asher**

2.5.2 Sample Analysis

Sample analysis requirements include an X-ray diffraction unit, equipped with:

- **Constant Potential Generator; Voltage and mA Stabilizers**
- **Automated Diffractometer with Step-Scanning Mode**
- **Copper Target X-Ray Tube:** High intensity; fine focus, preferably
- **X-Ray Pulse Height Selector**
- **X-Ray Detector** (with high voltage power supply); Scintillation or proportional counter

- **Focusing Graphite Crystal Monochromator;** or **Nickel Filter** (if copper source is used, and iron fluorescence is not a serious problem)
- **Data Output Accessories:**
Strip Chart Recorder
Decade Scaler/Timer
Digital Printer
- **Sample Spinner** (optional)
- **Instrument Calibration Reference Specimen:** α -quartz reference crystal (Arkansas quartz standard, #180-147-00, Philips Electronics Instruments, Inc., 85 McKee Drive, Mahwah, NJ 07430) or equivalent

2.6 Reagents

2.6.1 Standard Reference Materials

The reference materials listed below are intended to serve as a guide. Every attempt should be made to acquire pure reference materials that are comparable to sample materials being analyzed.

- **Chrysotile:** UICC Canadian, or NIEHS Plastibest. (UICC reference materials available from: UICC, MRC Pneumoconiosis Unit, Llandough Hospital, Penarth, Glamorgan, CF61XW, UK)
- **Crocidolite:** UICC
- **"Amosite":** UICC
- **Anthophyllite-Asbestos:** UICC
- **Tremolite Asbestos:** Wards Natural Science Establishment, Rochester, NY; Cyprus Research Standard, Cyprus Research, 2435 Military Ave., Los Angeles, CA 90064 (washed with dilute HCl to remove small amount of calcite impurity; Indian tremolite, Rajasthan State, India.
- **Actinolite Asbestos:** (Source to be determined).

2.6.2 Adhesive

Tape, petroleum jelly, etc. (for attaching silver membrane filters to sample holders).

2.6.3 Surfactant

1 Percent aerosol OT aqueous solution or equivalent.

2.6.4 Isopropanol

ACS Reagent Grade.

2.7 Procedure

2.7.1 Sampling

Samples for analysis of asbestos content shall be collected as specified in EPA Guidance Document #C0080, *Asbestos-Containing Materials in School Buildings*.¹⁸

2.7.2 Analysis

All samples must be analyzed initially for asbestos content by PLM. XRD should be used as an auxiliary method when a second, independent analysis is requested.

Note: Asbestos is a toxic substance. All handling of dry materials should be performed in an operating fume hood.

2.7.2.1 Sample Preparation

The method of sample preparation required for XRD analysis will depend on: (1) the condition of the sample received (sample size, homogeneity, particle size distribution, and overall composition as determined by PLM); and (2) the type of XRD analysis to be performed (qualitative or quantitative; thin layer or bulk).

Bulk materials are usually received as inhomogeneous mixtures of complex composition with very wide particle size distributions. Preparation of a homogeneous, representative sample from asbestos-containing materials is particularly difficult because the fibrous nature of the asbestos minerals inhibits mechanical mixing and stirring, and because milling procedures may cause adverse lattice alterations.

A discussion of specific matrix reduction procedures is given below. Complete methods of sample preparation are detailed in Sections 2.7.2.2 and 2.7.2.3. *Note: All samples should be examined microscopically before and after each matrix reduction step to monitor changes in sample particle size distribution, composition, and crystallinity, and to ensure sample representativeness and homogeneity for analysis.*

2.7.2.1.1 Milling—Mechanical milling of asbestos materials has been shown to decrease fiber crystallinity, with a resultant decrease in diffraction intensity of the specimen; the degree of lattice alteration is related to the duration and type of milling process.¹⁹⁻²² Therefore, all milling times should be kept to a minimum.

For qualitative analysis, particle size is not usually of critical importance and initial characterization of the material with a minimum of matrix reduction is often desirable to document the composition of the sample as received. Bulk samples of very large particle size (>2-3 mm) should be comminuted to ~100 μ m. A mortar and pestle can sometimes be used in size reduction of soft or loosely bound materials though this may cause matting of some samples. Such samples may be reduced by cutting with a razor blade in a mortar, or by grinding in a suitable mill (e.g., a microhammer mill or equivalent). When using a mortar for grinding or cutting, the sample should be moistened with ethanol, or some other suitable wetting agent, to minimize exposures.

For accurate, reproducible quantitative analysis, the particle size of both sample and standard materials should be reduced to ~10 μ m (see Section 2.3.3). Dry ball milling at liquid nitrogen temperatures (e.g., Spex Freezer Mill, or equivalent) for a maximum time of 10 min is recommended to obtain satisfactory particle size distributions while protecting the integrity of the crystal lattice.⁹ Bulk samples of very large particle size may require grinding in two stages for full matrix reduction to <10 μ m.^{9,10}

Final particle size distributions should always be verified by optical microscopy or another suitable method.

2.7.2.1.2 Low temperature ashing—For materials shown by PLM to contain large amounts of gypsum, cellulose, or other organic materials, it may be desirable to ash the samples prior to analysis to reduce background radiation or matrix interference. Since chrysotile undergoes dehydroxylation at temperatures between 550°C and 650°C, with subsequent transformation to forsterite,^{23,24} ashing temperatures should be kept below 500°C. Use of a low temperature ashier is recommended. In all cases, calibration of the oven is essential to ensure that a maximum ashing temperature of 500°C is not exceeded.

2.7.2.1.3 Acid leaching—Because of the interference caused by gypsum and some carbonates in the detection of asbestiform minerals by XRD (see Section 2.3.1), it may be necessary to remove these interferents by a simple acid leaching procedure prior to analysis (see Section 1.7.2.2).

2.7.2.2 Qualitative Analysis

2.7.2.2.1 Initial screening of bulk material—Qualitative analysis should be performed on a representative, homogeneous portion of the sample with a minimum of sample treatment using the following procedure:

1. Grind and mix the sample with a mortar and pestle (or equivalent method, see Section 2.7.2.1.1) to a final particle size sufficiently small (~100 μ m) to allow adequate packing into the sample holder.
2. Pack sample into a standard bulk sample holder. Care should be taken to ensure that a representative portion of the milled sample is selected for analysis. Particular care should be taken to avoid possible size segregation of the sample. (Note: Use of a back-packing method²⁵ for bulk sample

preparation may reduce preferred orientation effects.)

3. Mount the sample on the diffractometer and scan over the diagnostic peak regions for the serpentine (~7.4 Å) and amphibole (8.2-8.5 Å) minerals (see Table 2-2). The X-ray diffraction equipment should be optimized for intensity. A slow scanning speed of 1° 2θ/min is recommended for adequate resolution. Use of a sample spinner is recommended.
4. Submit all samples that exhibit diffraction peaks in the diagnostic regions for asbestiform minerals to a full qualitative XRD scan (5°-60° 2θ; 1° 2θ/min) to verify initial peak assignments and to identify potential matrix interferences when subsequent quantitative analysis is to be performed.
5. Compare the sample XRD pattern with standard reference powder diffraction patterns (i.e., JCPDS powder diffraction data³ or those of other well-characterized reference materials). Principal lattice spacings of asbestiform minerals are given in Table 2-2; common constituents of bulk insulation and wall materials are listed in Table 2-3.

2.7.2.2.2 Detection of minor or trace constituents—Routine screening of bulk materials by XRD may fail to detect small concentrations (<5 percent) of asbestos. The limits of detection will, in general, be improved if matrix absorption effects are minimized, and if the sample particle size is reduced to the optimal 1 to 10 μm range, provided that the crystal lattice is not degraded in the milling process. Therefore, in those instances where confirmation of the presence of an asbestiform mineral at very low levels is required, or where a negative result from initial screening of the bulk material by XRD (see Section 2.7.2.2.1) is in conflict with previous PLM results, it may be desirable to prepare the sample as described for quantitative analysis (see Section 2.7.2.3) and step-scan-over appropriate 2θ ranges of selected diagnostic peaks (Table 2-2). Accurate transfer of the sample to the silver membrane filter is not necessary unless subsequent quantitative analysis is to be performed.

2.7.2.3 Quantitative Analysis

The proposed method for quantitation of asbestos in bulk samples is a modification of the NIOSH-recommended thin-layer method for chrysotile in air.⁴ A thick-layer or bulk

method involving pelletizing the sample may be used for semiquantitative analysis;^{7,8} however, this method requires the addition of an internal standard, use of a specially fabricated sample press, and relatively large amounts of standard reference materials. Additional research is required to evaluate the comparability of thin- and thick-layer methods for quantitative asbestos analysis.

For quantitative analysis by thin-layer methods, the following procedure is recommended:

1. Mill and size all or a substantial representative portion of the sample as outlined in Section 2.7.2.1.1.
2. Dry at 100°C for 2 hr; cool in a desiccator.
3. Weigh accurately to the nearest 0.01 mg.
4. Samples shown by PLM to contain large amounts of cellulosic or other organic materials, gypsum, or carbonates, should be submitted to appropriate matrix reduction procedures described in Sections 2.7.2.1.2 and 2.7.2.1.3. After ashing and/or acid treatment, repeat the drying and weighing procedures described above, and determine the percent weight loss, L.
5. Quantitatively transfer an accurately weighed amount (50-100 mg) of the sample to a 1-L volumetric flask with approximately 200 mL isopropanol to which 3 to 4 drops of surfactant have been added.
6. Ultrasonicate for 10 min at a power density of approximately 0.1 W/mL, to disperse the sample material.
7. Dilute to volume with isopropanol.
8. Place flask on a magnetic stirring plate. Stir.
9. Place a silver membrane filter on the filtration apparatus, apply a vacuum, and attach the reservoir. Release the vacuum and add several milliliters of isopropanol to the reservoir. Vigorously hand shake the asbestos suspension and immediately withdraw an aliquot from the center of the suspension so that total sample weight, W_T, on the filter will be approximately 1 mg. Do not adjust the volume in the pipet by expelling part of the suspension; if more than the desired aliquot is withdrawn, discard the aliquot and resume the procedure with a

clean pipet. Transfer the aliquot to the reservoir. Filter rapidly under vacuum. Do not wash the reservoir walls. Leave the filter apparatus under vacuum until dry. Remove the reservoir, release the vacuum, and remove the filter with forceps. (Note: Water-soluble matrix interferences such as gypsum may be removed at this time by careful washing of the filtrate with distilled water. Extreme care should be taken not to disturb the sample.)

10. Attach the filter to a flat holder with a suitable adhesive and place on the diffractometer. Use of a sample spinner is recommended.
11. For each asbestos mineral to be quantitated, select a reflection (or reflections) that has been shown to be free from interferences by prior PLM or qualitative XRD analysis and that can be used unambiguously as an index of the amount of material present in the sample (see Table 2-2).
12. Analyze the selected diagnostic reflection(s) by step scanning in increments of 0.02° 2θ for an appropriate fixed time and integrating the counts. (A fixed count scan may be used alternatively; however, the method chosen should be used consistently for all samples and standards.) An appropriate scanning interval should be selected for each peak, and background corrections made. For a fixed time scan, measure the background on each side of the peak for one-half the peak-scanning time. The net intensity, I_n, is the difference between the peak integrated count and the total background count.
13. Determine the net count, I₀, of the filter 2.36 Å silver peak following the procedure in step 12. Remove the filter from the holder, reverse it, and reattach it to the holder. Determine the net count for the unattenuated silver peak, I₀. Scan times may be less for measurement of silver peaks than for sample peaks; however, they should be constant throughout the analysis.
14. Normalize all raw, net intensities (to correct for instrument instabilities) by referencing them to an external standard (e.g., the 3.34 Å peak of an α-quartz reference crystal). After each unknown is scanned, determine the net

count, I_p , of the reference specimen following the procedure in step 12. Determine the normalized intensities by dividing the peak intensities by I_p :

$$I_a = \frac{I_a}{I_p}, I_{a_0} = \frac{I_{a_0}}{I_p}, \text{ and } I_{a_0} = \frac{I_{a_0}}{I_p}$$

2.8 Calibration

2.8.1 Preparation of Calibration Standards

1. Mill and size standard asbestos materials according to the procedure outlined in Section 2.7.2.1.1. *Equivalent, standardized matrix reduction and sizing techniques should be used for both standard and sample materials.*
2. Dry at 100°C for 2 hr; cool in a desiccator.
3. Prepare two suspensions of each standard in isopropanol by weighing approximately 10 and 50 mg of the dry material to the nearest 0.01 mg. Quantitatively transfer each to a 1-L volumetric flask with approximately 200 mL isopropanol to which a few drops of surfactant have been added.
4. Ultrasonicate for 10 min at a power density of approximately 0.1 W/mL to disperse the asbestos material.
5. Dilute to volume with isopropanol.
6. Place the flask on a magnetic stirring plate. Stir.
7. Prepare, in triplicate, a series of at least five standard filters to cover the desired analytical range, using appropriate aliquots of the 10 and 50 mg/L suspensions. For each standard, mount a silver membrane filter on the filtration apparatus. Place a few mL of isopropanol in the reservoir. Vigorously hand shake the asbestos suspension and immediately withdraw an aliquot from the center of the suspension. Do not adjust the volume in the pipet by expelling part of the suspension; if more than the desired aliquot is withdrawn, discard the aliquot and resume the procedure with a clean pipet. Transfer the aliquot to the reservoir. Keep the tip of the pipet near the surface of the isopropanol. Filter rapidly under vacuum. Do not wash the sides of the reservoir. Leave the vacuum on for a time sufficient to dry the filter. Release the vacuum and remove the filter with forceps.

2.8.2 Analysis of Calibration Standards

1. Mount each filter on a flat holder. Perform step scans on selected diagnostic reflections of the standards and reference specimen using the procedure outlined in Section 2.7.2.3, step 12, and the same conditions as those used for the samples.
2. Determine the normalized intensity for each peak measured, I_{a_0} , as outlined in Section 2.7.2.3, step 14.

2.9 Calculations

For each asbestos reference material, calculate the exact weight deposited on each standard filter from the concentrations of the standard suspensions and aliquot volumes. Record the weight, w , of each standard. Prepare a calibration curve by regressing I_{a_0} on w . Poor reproducibility (± 15 percent RSD) at any given level indicates problems in the sample preparation technique, and a need for new standards. The data should fit a straight line equation.

Determine the slope, m , of the calibration curve in counts/microgram. The intercept, b , of the line with the I_{a_0} axis should be approximately zero. A large negative intercept indicates an error in determining the background. This may arise from incorrectly measuring the baseline or from interference by another phase at the angle of background measurement. A large positive intercept indicates an error in determining the baseline or that an impurity is included in the measured peak.

Using the normalized intensity, I_{a_0} , for the attenuated silver peak of a sample, and the corresponding normalized intensity from the unattenuated silver peak, I_{a_0} , of the sample filter, calculate the transmittance, T , for each sample as follows:

$$T = \frac{I_{a_0}}{I_{a_0}}$$

Determine the correction factor, $f(T)$, for each sample according to the formula:

$$f(T) = \frac{-R(\ln T)}{1-T}$$

where

$$R = \frac{\sin \theta_{a_0}}{\sin \theta_a}$$

θ_{a_0} = angular position of the measured silver peak (from Bragg's Law), and
 θ_a = angular position of the diagnostic asbestos peak.

Calculate the weight, W_a , in micrograms, of the asbestos material analyzed for in each sample, using the appropriate calibration data and absorption corrections:

$$W_a = \frac{I_a f(T) - b}{m}$$

Calculate the percent composition, P_a , of each asbestos mineral analyzed for in the parent material, from the total sample weight, W_T , on the filter:

$$P_a = \frac{W_a (1 - 0.01L)}{W_T} \times 100$$

where

P_a = percent asbestos mineral in parent material;

W_a = mass of asbestos mineral on filter, in μg ;

W_T = total sample weight on filter, in μg ;

L = percent weight loss of parent material on ashing and/or acid treatment (see Section 2.7.2.3).

2.10 References

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Table 2-1. The asbestos minerals and their nonasbestiform analogs.

Asbestiform	Nonasbestiform
Serpentine	
Chrysotile	Antigorite, lizardite
Amphibole	
Anthophyllite asbestos	Anthophyllite
Cummingtonite-grunerite asbestos ("Amosite")	Cummingtonite-grunerite
Crocidolite	Riebeckite
Tremolite asbestos	Tremolite
Actinolite asbestos	Actinolite

Table 2-2. Principal lattice spacings of asbestiform minerals.^a

Minerals	Principal d-spacings (Å) and relative intensities			JCPDS Powder diffraction file ^c number
Chrysotile	7.37 ₁₀₀	3.65 ₇₀	4.57 ₅₀	21-543 ^c
	7.36 ₁₀₀	3.66 ₈₀	2.45 ₈₀	25-645
	7.10 ₁₀₀	2.33 ₈₀	3.55 ₇₀	22-1162 (theoretical)
"Amosite"	8.33 ₁₀₀	3.06 ₇₀	2.756 ₇₀	17-745 (nonfibrous)
	8.22 ₁₀₀	3.060 ₈₀	3.25 ₇₀	27-1170 (UICC)
Anthophyllite	3.05 ₁₀₀	3.24 ₈₀	8.26 ₅₀	9-455
	3.06 ₁₀₀	8.33 ₇₀	3.23 ₈₀	16-401 (synthetic)
Actinolite	2.72 ₁₀₀	2.54 ₁₀₀	3.40 ₈₀	25-157
Crocidolite	8.35 ₁₀₀	3.10 ₅₀	2.720 ₅₀	27-1415 (UICC)
Tremolite	8.38 ₁₀₀	3.12 ₁₀₀	2.705 ₈₀	13-437 ^c
	2.706 ₁₀₀	3.14 ₈₀	8.43 ₈₀	20-1310 ^c (synthetic)
	3.13 ₁₀₀	2.706 ₈₀	8.44 ₈₀	23-666 (synthetic mixture with richterite)

^aThis information is intended as a guide, only. Complete powder diffraction data, including mineral type and source, should be referred to, to ensure comparability of sample and reference materials where possible. Additional precision XRD data on amosite, crocidolite, tremolite, and chrysotile are available from the U.S. Bureau of Mines, References 4.

^bFrom Reference 3.

^cFibrosity questionable.

Table 2-3. Common constituents in insulation and wall materials (from Ref. 10)

A. Insulation materials	B. Spray finishes or paints
Chrysotile	Bassanite
"Amosite"	Carbonate minerals (talcite, dolomite, vaterite)
Crocidolite	Talc
*Rock wool	Tremolite
*Slag wool	Anthophyllite
*Fiber glass	Serpentine (including chrysotile)
Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)	*Amosite*
Vermiculite (micas)	Crocidolite
*Perlite	*Mineral wool
Clays (kaolin)	*Rock wool
*Wood pulp	*Slag wool
*Paper fibers (talc, clay, carbonate fillers)	*Fiber glass
Calcium silicates (synthetic)	Clays (kaolin)
Opaques (chromite, magnetite inclusions in serpentine)	Micas
Hematite (inclusions in "amosite")	Chlorite
Magnetite	Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)
*Diatomaceous earth	Quartz
	*Organic binders and thickeners
	Hydromagnesite
	Wollastonite
	Opaques (chromite, magnetite inclusions in serpentine)
	Hematite (inclusions in "amosite")

*Amorphous materials--contribute only to overall scattered radiation and increased background radiation.

Table 2-4. Interferences in XRD analysis of asbestiform minerals

Asbestiform mineral	Primary diagnostic peaks (approximate d-spacings in Å)	Interference
Serpentine		
Chrysotile	7.4	Nonasbestiform serpentines (antigorite, lizardite)
		Chlorite
		Kaolinite
		Gypsum
	3.7	Nonasbestiform serpentines, (antigorite, lizardite)
		Chlorite
		Halloysite
		Cellulose
Amphibole		
"Amosite"	3.1	Nonasbestiform amphiboles (cummingtonite-grunerite, anthophyllite, riebeckite, tremolite)
Anthophyllite		Mutual interferences
Crocidolite		Carbonates
Tremolite		Talc
	8.3	Nonasbestiform amphiboles (cummingtonite, grunerite, anthophyllite, riebeckite, tremolite)
		Mutual interferences

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