Miller, Diane M. (CDC/NIOSH/EID)

From: Mark Ellis [markellis@ima-na.org]
Sent: Wednesday, May 30, 2007 6:26 PM
To: NIOSH Docket Office (CDC)
Cc: markellis@ima-na.org
Subject: NIOSH Docket Number NIOSH-099
Importance: High
Attachments: NIOSH Roadmap - Comments.doc

Ms. Miller--

Please find attached the comments of the Industrial Minerals Association - North America (IMA-NA) on the National Institute for Occupational Safety and Health's (NIOSH) **Draft Document: *Asbestos and Other Mineral Fibers: A Roadmap for Scientific Research;* NIOSH Docket Number NIOSH-099.**

Should you have any questions regarding the comments, please do not hesitate to contact me.

Sincerely--

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Industrial Minerals Association — North America

May 30, 2007

Ms. Diane Miller
NIOSH Docket Office
Robert A. Taft Laboratories
4676 Columbia Parkway, MS C-34
Cincinnati, OH 45226

RE: Draft Document: *Asbestos and Other Mineral Fibers: A Roadmap for Scientific Research;* NIOSH Docket Number NIOSH-099

Dear Ms. Miller:

The Industrial Minerals Association – North America (IMA-NA) is a Washington, DC area-based trade association created to advance the interests of North American companies that mine or process minerals used throughout the manufacturing and agricultural industries. IMA-NA membership also is open to companies that provide equipment and services to the industry.

IMA-NA has reviewed the above-referenced Draft Document (Roadmap) by the National Institute for Occupational Safety and Health (NIOSH) and is pleased to offer the following comments.

At the outset, IMA-NA wishes to commend NIOSH for the contributions it has made to promoting occupational safety and health. The NIOSH Roadmap document on asbestos research has the potential to make additional contributions in the area of occupational health, but requires modification.

IMA-NA is on record as supporting regulatory changes to better protect workers potentially exposed to asbestos hazards on the job, particularly miners. For instance, IMA-NA concurs with the key provisions of the current proposal by the Mine Safety and Health Administration (MSHA) to update is regulation of asbestos. Specifically, IMA-NA supports the reduction of the MSHA permissible exposure limit (PEL) for full-shift exposures and the excursion limit earlier adopted for asbestos by the Occupational Health and Safety Administration (OSHA). IMA-NA further supports the continued use of phase contrast microscopy (PCM) for initial quantification of asbestos fibers in air with the use of transmission electron microscopy (TEM) as needed to aid in the identification of asbestos. IMA-NA also supports MSHA's proposed approach to control take-home asbestos contamination on work clothing.

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In aligning its proposed rule with the OSHA asbestos standard, MSHA accepted OSHA's risk assessment in lieu of conducting its own. However, IMA-NA would support the inclusion of other asbestiform amphibole minerals if they clearly demonstrate a health risk similar in magnitude and scope to the asbestiform amphiboles currently regulated as asbestos and to which miners are exposed. Extension of this proposal to all mining environments appears reasonable as well.

IMA-NA first takes exception to the term "fiber-like" cleavage fragments that NIOSH utilizes throughout the Roadmap document. The term is a misnomer and misleading. Its continued inadvertent and improper use may lead to treating elongated amphibole cleavage fragments as asbestos fibers. Specifically, IMA-NA is concerned about the possible application of an arbitrary fiber-counting criteria to "define" asbestos rather than to simply count asbestos fibers once identified. This unintended outcome would run counter to cleavage fragment health science.

The "cleavage fragment issue" (as it is often called) has a long and often contentious history. For this reason IMA-NA and many others commented extensively on this issue during MSHA's Advance Notice of Proposed Rulemaking (ANPRM). MSHA is fortunate to have a 1992 OSHA rulemaking to review that includes a risk analysis specific to amphibole cleavage fragments. 57 FR 24310-24331. We encourage NIOSH to fully review that OSHA rulemaking proceeding and have attached a copy for your convenience (**Attachment 1**).

The adoption of an overly broad asbestos definition could transform major portions of the earths crust into asbestos and cause significant harm to segments of the mining and aggregates industries with no offsetting benefit to miners' health. The impact of regulating amphibole cleavage fragments as asbestos was described by the Bureau of Mines (BOM) in it's submission to the OSHA rulemaking docket in 1989. A copy of the BOM impact statement is appended (**Attachment 2**).

IMA-NA hopes NIOSH understands that the analytical methodology for the quantification of asbestos fibers in air is not specific to asbestos. We are, in fact, aware of no analytical method that is specific to asbestos. The commonly applied NIOSH PCM method 7400, NIOSH TEM method 7402, OSHA ID-160 (the PCM method that MSHA specifically incorporates through OSHA Appendix A), for example, properly state that elongated cleavage fragments are "interferences" when used for asbestos quantification (see **Attachment 3** – highlighted statements in methods). Even when applied by accredited laboratories, available analytical methods will not identify asbestos consistently and reliably ***for the analyst.*** Instead, it is knowledge of the nature of asbestos and its appreciation ***by the analyst*** that most influences the consistency and reliability of asbestos identification.

Several highly regarded mineral scientists (Dr's Wylie, Lee, Chatfield and Ross) testified before MSHA during the ANPRM phase of this rulemaking. These experts have researched and published on the mineral characteristics of asbestos for decades and appeared at the request of the National Stone, Sand and Gravel Association (NSSGA). These highly experienced analysts also cautioned MSHA that there currently is no analytical method specific to asbestos and that existing methods are only tools ***that aid*** in the identification and quantification of asbestos when

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the fiber exposure is not known 'a priori' to be asbestos (as is often the case in mining environments).

These analysts also recommended analytical modifications that would improve specificity in the qualification and quantification of asbestos. These modifications spoke principally to PCM differential fiber-size counting criteria that are more specific to asbestos (an identification approach recommended in OSHA's own Appendix B ID-160 PCM method – see Attachment 3). **Attachment 4** to this submission provides several quotes from the testimony of these experts which we feel reinforce our concerns. IMA-NA encourages NIOSH to review the full oral testimony and written comments of these noted scientists.

Given the above concerns, IMA-NA is pleased to submit the following specific recommendations:

1. The NIOSH Roadmap document should include an accurate and complete description of the asbestiform and nonasbestiform crystal growth habit. We suggest a consensus definition that appeared in one of our submissions for the MSHA ANPRM entitled: "*The Asbestiform and Nonasbestiform Mineral Growth Habit and Their Relationship to Cancer Studies*." We are submitting this document to NIOSH as it addresses the key mineralogical distinctions clearly and concisely, provides a review of the pertinent health science base and a differential fiber counting PCM method "more" specific to asbestos (see **Attachment 5)**. Please note a listing of the contributors and supporters of this consensus definition on page 64 of that document relative to their backgrounds and qualifications as geologists and mineral scientists. IMA-NA supports calling any substance by its proper name and regulating that substance on the basis of its demonstrated adverse health effects. IMA-NA does not view "difficulty" as a viable justification to mischaracterize exposures, but rather as a reason to make needed advancements.

2. As no analytical method is specific to asbestos, IMA-NA suggests encouraging the use of all available scientific literature and mineralogical expertise to complement existing analytical methods. Until such time as an asbestos-specific analytical protocol is developed, all available tools must be used in equivocal exposure circumstances (when the exposure is not known 'a priori' to be an asbestos exposure). IMA-NA believes the scientific literature in regard to distinguishing asbestos fibers from elongated nonasbestiform fibers is reasonably extensive and should be consulted. One reference example (which also addresses amphibole from Libby, Montana) can be found in **Attachment 6.**

3. NIOSH further should provide guidance to help the regulated community make this key distinction by adopting the steps taken by OSHA to enhance the reliability of identification when needed. OSHA allows for "differential" fiber counting to provide latitude to the analyst to use his/her expertise and all available information helpful in making the proper distinctions. OSHA further allows and encourages the use of Polarized Light Microscopy (PLM) bulk analysis applied by qualified individuals as another tool to be used in the identification of asbestos. OSHA includes Appendix C in

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its asbestos standard for this purpose (see **Attachment 7).** This Appendix C PLM method includes additional descriptive guidance that aids the analyst in the identification of asbestos. **Attachment 8** contains 1989 correspondence from the OSHA laboratory that outlines how the agency analytically addresses this matter.

In recommending the use of bulk analysis, IMA-NA is not suggesting bulk analysis be used in place of air sampling (recognizing the regulatory compliance aspect of air sampling), but rather as an additional tool to enable the analyst to properly characterize the exposure. Of course if representative bulk analysis clearly shows the absence of asbestos, the need for air sampling can be better assessed. Analysts consistently testify that it is much easier to identify asbestos in bulk material (where the full range of asbestiform growth characteristics is commonly seen) than based on a few "fibers" or a single fiber on an air filter. Again, the characteristics of asbestiform fibers (widths independent of length, polyfilamentous bundling of fibrils, etc.) are best seen on a population basis (the bigger the population, the easier to distinguish). Such characteristics extend beyond merely "parallel sides" (also observed among cleavage fragments). Proper discrimination of fibers, of course, becomes a more critical issue as the PEL is reduced.

4. IMA-NA encourages the review of all available geological information on ore deposits to better understand the nature of mining exposures as well. We view this advice of particular importance to MSHA given the complexity of many mining environments and, therefore, the increased likelihood of identification questions.

The NIOSH Roadmap document notes that IMA-NA and NSSGA have suggested other procedures with the intent that fiber counts on air samples do not include cleavage fragments. Roadmap at page18. Stated somewhat differently, IMA and NSSGA have suggested other procedures with the intent that fiber counts on air samples do not include cleavage fragments as asbestos. The NIOSH Roadmap goes on to state that whether these suggested procedures would assure adequate health protections for exposed workers is unclear, and the practical issues associated with implementing these supplemental procedures are also undetermined.

IMA-NA submits that it is just these types of issues that the NIOSH Roadmap document can, and should, address. The NIOSH research agenda should not be dictated by adherence to definitions and analytical techniques developed in the past that fail to meet current realities and needs. IMA-NA would be pleased to work with NIOSH to develop a research agenda to better define asbestos and to differentiate asbestos from amphibole cleavage fragments.

To that end, IMA-NA reiterates for NIOSH the recommendations made to MSHA to improve its proposed asbestos rule:

56.5001 (amended) – 57.5001 (amended) and 71.702

(b) *Asbestos standard.*

(1) Definitions. Asbestos is a generic term for a number of hydrated silicates that, when crushed or processed, separate into flexible fibers made up of fibrils. As used in this part –

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Asbestos means chrysotile, amosite (cummingtonite-grunerite asbestos) crocidolite, anthophyllite asbestos, tremolite asbestos and actinolite asbestos **and does not include non-fibrous or nonasbestiform minerals**.

***Asbestiform* means a mineral that crystallized with the habit (morphology) of asbestos. The asbestiform crystal growth habit is generally recognized by the following characteristics which are best observed on a population basis and therefore best observed in bulk samples:**

Mean fiber aspect (length to width) ratios ranging from 20:1 to 100:1 or higher for fibers longer than 5 micrometers. Very thin fibrils, usually less than 0.5 micrometers in width, and two or more of the following:

- **Parallel fibers occurring in bundles**
- **Fiber bundles displaying splayed ends**
- **Matted masses of individual fibers and/or**
- **Fibers showing curvature**

***Fiber Counting Criteria* are 5 micrometers (μm) or longer with a length-to-diameter ratio of at least 3:1.**

(2) Permissible Exposure Limits (PELs). – (i), (ii) - (no change recommended)

*(3) Measurement of **Asbestos**.* **Airborne asbestos** fiber concentration shall be determined by phase contrast microscopy using a method statistically equivalent to the OSHA Reference Method in OSHA's asbestos standard found in 29 CFR 1910.1001, appendix A **when the exposure is known 'a priori' to be only commercial asbestos (not mixed dust).**

When a fiber exposure is not known to be asbestos (or is otherwise equivocal) or is a mixed dust exposure, additional investigation is necessary because no currently available analytical method is specific to airborne asbestos. This additional investigation shall include the following:

- **Review of available geological information for the identification of regulated asbestiform mineral occurrences in the mining deposit.**

- **The analysis of bulk samples (ore, insulation, settled dust, etc.) that is representative of the miner's work area exposure. OSHA appendix C 29 CFR 1910.1001 (Polarized Light Microscopy Method) or an equivalent method, shall be used for bulk analysis. The absence of asbestos in bulk samples shall eliminate the need for air sampling and/or analysis of particulate on air filters. The presence of asbestos in the bulk sample at any level will require personal air sampling or analysis of collected air samples.**

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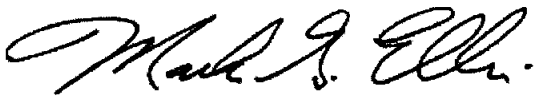
- **On air samples analyzed by PCM or TEM, the characteristics of asbestos fibers defined in section (b) 1 above, described in OSHA appendix C and supported in OSHA appendix B, shall be observed.**

- **Bulk and air samples that have been analyzed with results indicating the presence of asbestos at any level, shall be retained for a period of no less than one year for possible reanalysis. This sample retention requirement will be applied to mine operator and MSHA collected samples.**

In summary IMA-NA believes there is need for caution in this area because current analytical methods are not specific to asbestos and this poses a significant problem for the mining community (especially with a reduced PEL). The proper identification of asbestos calls for enhanced education, improved methodology, and better use of the existing knowledge base regarding the nature of asbestos. IMA-NA believes NIOSH is in a unique position to highlight and support these needed improvements.

Respectfully submitted,



Mark G. Ellis
President

Attachments

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Attachments to Comments

of the

Industrial Minerals Association – North America

on the

National Institute for Occupational Safety and Health

Draft Document

Asbestos and Other Mineral Fibers: A Roadmap for Scientific Research

(Click on link to view attachment)

Attachment 1
http://www.msha.gov/regs/comments/05-14510/AB24-COMM-107-1.pdf

Attachment 2
http://www.msha.gov/regs/comments/05-14510/AB24-COMM-107-2.pdf

Attachment 3
http://www.msha.gov/regs/comments/05-14510/AB24-COMM-107-3.pdf

Attachment 4
http://www.msha.gov/regs/comments/05-14510/AB24-COMM-107-4.pdf

Attachment 5
http://www.msha.gov/regs/comments/05-14510/AB24-COMM-107-5.pdf

Attachment 6
http://www.msha.gov/regs/comments/05-14510/AB24-COMM-107-6.pdf

Attachment 7
http://www.msha.gov/regs/comments/05-14510/AB24-COMM-107-7.pdf

Attachment 8
http://www.msha.gov/regs/comments/05-14510/AB24-COMM-107-8.pdf

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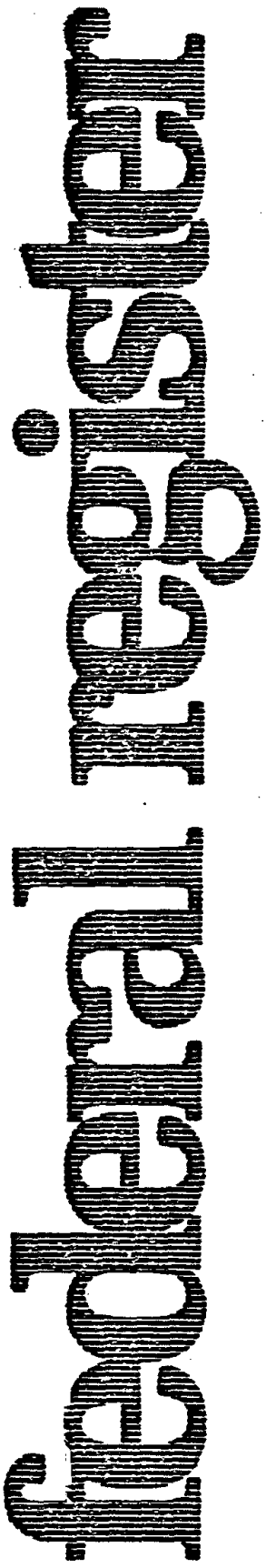
ATTACHMENT 1



Mon
June 8, 1992

Part II

Department of Labor

Occupational Safety and Health Administration

29 CFR Parts 1910 and 1926

Occupational Exposure to Asbestos, Tremolite, Anthophyllite and Actinolite; Final Rule

DEPARTMENT OF LABOR

Occupational Safety and Health Administration

29 CFR Parts 1910 and 1926

[Docket No. H-033-d]

Occupational Exposure to Asbestos, Tremolite, Anthophyllite and Actinolite

AGENCY: Occupational Safety and Health Administration, Labor.

ACTION: Final rule.

SUMMARY: In this final standard the Occupational Safety and Health Administration (OSHA) amends its present standards for regulating occupational exposure to asbestos in general industry (29 CFR 1910.1001) and construction (29 CFR 1928.56).

OSHA has reviewed available relevant evidence concerning the health effects of nonasbestiform tremolite, anthophyllite and actinolite and has also examined the feasibility of various regulatory options. Based on the entire rulemaking record before it, OSHA has made a determination that substantial evidence is lacking to conclude that nonasbestiform tremolite, anthophyllite and actinolite present the same type or magnitude of health effect as asbestos. Further, substantial evidence does not support a finding that exposed employees would be at a significant risk because nonasbestiform tremolite, anthophyllite or actinolite was not regulated in the asbestos standards.

OSHA hereby lifts the Administrative Stay, removes and reserves 29 CFR 1910.1101, and amends the revised asbestos standards to remove nonasbestiform tremolite, anthophyllite and actinolite from their scope.

DATES: *Effective date:* This final rule shall become effective May 29, 1992.

Administrative stay: The Administrative Stay expired May 30, 1992.

ADDRESSES: For additional copies of this document, contact OSHA Office of Publications; U.S. Department of Labor, room N-3101, 200 Constitution Ave., NW., Washington, DC 20210, Telephone (202)-523-9667.

For copies of materials in the docket, contact: OSHA Docket Office, Docket No. H-033d, U.S. Department of Labor, room N-2625, 200 Constitution Ave., NW., Washington, DC 20210, Telephone (202)-523-7894. The hours of operation of the Docket Office are 10 a.m. until 4 p.m.

In compliance with 28 U.S.C. 2112(a), the Agency designates for receipt of petitions for review of this final decision, under section 6(f) of the OSH Act, the Associate Solicitor for Occupational Safety and Health, Office of the Solicitor, room S-4004, U.S. Department of Labor, 200 Constitution Ave., NW., Washington, DC 20210.

FOR FURTHER INFORMATION CONTACT: James F. Foster, Director of Information and Consumer Affairs, Occupational Safety and Health Administration, U.S. Department of Labor, room N-3649, 200 Constitution Avenue, NW., Washington, DC 20210, telephone (202) 523-8151.

SUPPLEMENTARY INFORMATION:

Table of Contents

I. Introduction

This preamble discusses OSHA's decision to remove nonasbestiform tremolite, anthophyllite, and actinolite (herein referred to as ATA and/or nonasbestiform ATA) from the asbestos standards for general industry and construction (29 CFR 1910.1001 and 1926.58). Instead, exposure to nonasbestiform ATA will be regulated by the particulates not otherwise regulated (PNOR) limit in Table Z-1-A of 1910.1000 [15 mg/m^3 (total dust); 5 mg/m^3 (respirable dust)]. Becuase nonasbestiform ATA is found in combination with other minerals, some of which are regulated by other exposure limits in Table Z-1-A, some employees exposed to nonasbestiform ATA will be protected by those exposure limits as well.

OSHA is also removing and reserving 29 CFR 1910.1101, which was designated "Asbestos" and which has been applied to nonasbestiform ATA during the administrative stay of the revised asbestos standards (29 CFR 1910.1001 and 29 CFR 1926.58). OSHA has determined that the 1972 asbestos standard, which had been redesignated 1910.1101, no longer applies to nonasbestiform ATA and thus, there is no current reason to continue to include it in the Code of Federal Regulations.

As discussed further in this preamble, OSHA's determination to remove nonasbestiform ATA from the scope of the asbestos standards, is based on the insufficiency of evidence to support determinations that their further inclusion would protect exposed employees from a risk of disease which was the equivalent in incidence and gravity to asbestos related disease, and that removing coverage would pose a significant risk to exposed employees.

The Agency also finds that the evidence is insufficient to regulate nonasbestiform ATA as presenting a significant health risk to employees other than as a physical irritant, without regard to its analogy to asbestos. Thus no separate standard is necessary at this time and the PNOR limit is appropriate.

In summary the basis for these findings is as follows. Asbestos and nonasbestiform ATA appear to be distinguishable mineral entities on a population basis, and in most instances on a particle basis. The characteristics which differentiate them generally appear to correspond to the properties which may dictate different biologic response. There are mechanistic data from experimental animals exposed to various durable minerals which support counting some particles of nonasbestiform ATA like all asbestos fibers. However, available toxicological and epidemiologic evidence related specifically to nonasbestiform ATA is negative or inconclusive on the issue. Also, in most cases, particles of nonasbestiform ATA appear to be a very small fraction of the dust population to which employees are exposed. Therefore, OSHA finds there is insufficient evidence to support regulating nonasbestiform ATA as presenting a risk similar in kind and extent to asbestos.

Regulating nonasbestiform ATA on its own is also precluded by the limitations of the available evidence. Dose response data concerning nonasbestiform ATA exposure alone is not available; human and animal studies concerning nonasbestiform ATA are individually and collectively, equivocal. Most of the studies do not, on their face report results which show a statistically significant positive response due to nonasbestiform ATA exposure. Criticisms concerning their interpretation mainly concern their power to disprove an association between nonasbestiform ATA exposure and abestos-related disease. OSHA finds that even if these criticisms are accepted, the totality of evidence still does not constitute affirmative evidence supporting regulating nonasbestiform ATA as presenting a significant health risk.

This rulemaking record therefore is distinguishable from the body of evidence in the EtO rulemaking which was considered "compelling" in the aggregate, although most of the studies were individually flawed. *(Public Citizen Health Research Group* v.

Tyson, 796 F2d 1479). Accordingly, the Agency has determined to not regulate nonasbestiform ATA exposure in a separate standard, since it is unable to conclude, given the information currently available, that it presents a significant risk to exposed employees, at current exposure levels, at any of the asbestos PELs which applied during the history of asbestos standards, or at any other specific level.

OSHA also believes that evidence in this record does not show that removing nonasbestiform ATA from the scope of the asbestos standards will pose a significant risk to exposed employees. As discussed later in this document, testimony and evidence which is not controverted, indicates that, although there is a risk of nonmalignant respiratory disease from high exposures to talc containing nonasbestiform ATA. (See discussion during regulatory alternatives), nonasbestiform ATA is not identified as the causative agent of such nonmalignant disease. OSHA has also determined that there is insufficient health effects evidence linking exposure to nonasbestiform ATA to a heightened risk of cancer. Historic exposure levels of talc containing nonasbestiform ATA (converted from mppcf) linked to production of excess nonmalignant disease have been estimated as approximately 4 to 12 mg/m ^{3}. At levels estimated at approximately 1.5 to 6.5 mg/m ^{3} (Ex. 84–141, docket H–033c, Kleinfeld et al., at 665; conversion made by ACGIH 1986) excess nonmalignant respiratory disease appears to be eliminated. The current PEL for talc is 2 mg/m ^{3}. (Talc is measured on a gravimetric basis rather than by fiber and is thus measured in mg/m ^{3}.)

Without inclusion in the asbestos standards, employees exposed to nonasbestiform ATA will be covered by various dust limits in OSHA's Air Contaminant Standards (29 CFR 1910.1000 and 29 CFR 1926.55). Those employees exposed to tremolitic talc, will be covered by the talc standard as well, for that fraction of their exposure which constitutes talc. Where exposure occurs to a mixture of substances the mixture formula in the Air Contaminant Standard applies. Therefore workers exposed to nonasbestiform ATA contaminated talc, the commercial product most likely to contain sizable amounts of nonasbestiform ATA, will be protected by several permissible exposure limits and hazard communication provisions.

The other industries where nonasbestiform ATA exposure occur are those where ATA are constituents of crushed rock and stone. At the time of the proposal, OSHA's contractor reported the following conclusions about the potential for exposure to nonasbestiform ATA in industries which consume crushed stone, sand, and gravel. "The occurrence of nonasbestiform tremolite, actinolite, and/or anthophyllite is erratic and unpredictable. However, when it does occur—even in significant quantities—it does not appear that construction or other activities which disrupt the minerals and produce dust result in airborne fiber levels which exceed OSHA's action level 0.1 f/cc. "(CONSAD report, Ex. 465 at 1.14). (In this example, particles of nonasbestiform ATA, which are greater than 5 microns in length and have aspect ratios greater than or equal to 3:1, are measured as "fibers/cc" as opposed to the example above where dust was measured on a gravimetric basis.)

No evidence was presented in the rulemaking which showed that workers will be exposed to airborne levels of nonasbestiform ATA during activities involving crushed rock or stone which significantly exceed CONSAD's estimate. Therefore, OSHA concludes that removing these workers from the protection of the asbestos standard will not result in a significant health risk to them because, even if workers were exposed to levels estimated by OSHA's contractor, there would likely be no significant risk.

The Agency acknowledges that certain public health organizations have recommended that OSHA continue to regulate nonasbestiform ATA under the asbestos standards. Thus, the American Thoracic Society (ATS) concluded that "(a)t present, the prudent public health policy course is to regard appropriately sized (non-asbestiform) tremolite "fibers" in sufficient exposure dose (concentration and duration), as capable of producing the recognized asbestos-related diseases, and they should be regulated accordingly. (Ex. 525 at 15). As discussed in detail in the section on mineralogy, OSHA continues to believe that fiber dimension is the most significant indicator of fiber pathology. However, there is insufficient evidence in the record to determine the parameters of "appropriately sized" tremolite particles. In addition the evidence which is available most likely associates fibers with dimensions common to asbestos populations with disease causing potential than particles found in nonasbestiform ATA populations. For example, the Stanton index particle of at least 8 μm in length and less than .25 μm in width, is rarely associated with nonasbestiform ATA particles, but is a common dimension for asbestos fibers.

NIOSH also recommends that OSHA continue to regulate nonasbestiform ATA under the asbestos standards. Its major rationale is similar to the ATS's, i.e. "NIOSH concludes for regulatory purposes that cleavage fragments of the appropriate aspect ratio and length from the nonasbestiform minerals should be considered as hazardous as fibers from the asbestiform minerals." (Tr. 5/9, p. 9). As stated above, OSHA does not believe that the current record provides an evidentiary basis to determine "the appropriate aspect ratio and length," for determining pathogenicity. Even if dimensional cut-offs were known for asbestos fibers, additional data do not support a standard for all ATA minerals based on fiber dimension alone. Available data show that asbestos containing dusts have much greater potency than non-asbestos containing dusts. Nor is there direct evidence showing fiber equivalency for asbestos and nonasbestiform ATA. NIOSH's additional concern is that by deregulating nonasbestiform ATA, OSHA will leave unprotected workers who may be exposed to asbestos, as a contaminant of a nonasbestiform mineral deposit or product to which they are exposed. (See Tr. 5/9, pp. 10–14). In this regard OSHA notes that available evidence indicates that significant contamination of nonasbestiform mineral deposits is identifiable and thus amenable to regulations under applicable asbestos standards.

Thus, OSHA does not believe that potential asbestos contamination of nonasbestos minerals, including nonasbestiform ATA, is sufficient reason to include such nonasbestiform minerals in the asbestos standard. If the presence of asbestos is known, it should be evaluated for extent and exposure potential. The definition of asbestos in the asbestos standards, and the counting criteria therein are sufficiently broad so as to cover all identifiable asbestos fibers. As discussed later in this document, OSHA has not changed these provisions. If an identification error is made, it is likely to be a false positive for asbestos rather than a false negative. Airborne exposure data in the record relating to naturally occurring asbestos as a contaminant, show that exposure potential is likely to be very low, even where asbestos is a major contaminant. (CONSAD study, Ex. 465)

Also, answering NIOSH's concerns, evidence in the record shows that differential analysis of mineral deposits and products can and is being performed using a variety of methods.

(See Langer, Tr. 5/11, pp. 225–227). Based on these considerations, OSHA does not believe that including nonasbestiform ATA in the asbestos standards in order to insure that asbestos contamination of nonasbestiform ATA deposits will not be ignored is necessary to protect employees exposed to mineral products where asbestos contamination is a possibility. In consequence of this decision ATA will be regulated as a PNOR at 5 mg/m³ or 15 mg/m³ because of physical irritation. Because a mixture of talc and nonasbestiform ATA has been shown to cause nonmalignant respiratory disease, the mixture formula clearly is applicable.

Paperwork Reduction

In accordance with the Paperwork Reduction Act of 1980 (44 U.S.C. *et seq.*), and the regulations issued pursuant thereto (5 CFR part 1320), OSHA is required to submit the information collection requirements contained in its standards to the Office of Management and Budget (OMB) for review under section 3504(h) of the Act. However, in this final there are no information collection requirements.

Federalism

This document has been reviewed in accordance with Executive Order 12612, 52 FR 41685 (October 30, 1987), regarding Federalism. This Order requires that agencies, to the extent possible, refrain from limiting state policy options, consult with States prior to taking any actions that would restrict actions only when there is a clear Congressional intent for the agency to do so. Any such preemption is to be limited to the extent possible.

Section 18 of the Occupational Safety and Health Act (OSH Act), expresses Congress' clear intent to preempt State laws with respect to which Federal OSHA has promulgated occupational safety or health standards. Under the OSH Act a State can avoid preemption only if it submits, and obtains Federal approval of a plan for the development of such standards and their enforcement. Occupational safety and health standards developed by such Plan-States must, among other things, be at least as effective as the Federal standards in providing safe and healthful employment and places of employment.

To the extent that there are any State or regional peculiarities, States with occupational safety and health plans approved under Section 18 of the OSH Act would be able to develop their own State standards to deal with any special problems.

Those States which have elected to participate under Section 18 of the OSH Act would not be preempted by this final standard and would be able to deal with special, local conditions within the framework provided by this standard while ensuring that their standards are at least as effective as the Federal standard.

State Plans

The 23 States and 2 territories with their own OSHA-approved occupational safety and health plans must adopt a comparable standard (i.e. a standard which is at least as effective as the federal standard) within 6 months after the publication of a final standard for occupational exposure to nonasbestiform ATA or amend their existing standard if it is not "at least as effective" as the final federal standard. States with their own OSHA-approved occupational safety and health plans may also elect to be more protective than the federal standard. The states and territories with occupational safety and health state plans are Alaska, Arizona, California, Connecticut, Hawaii, Indiana, Iowa, Kentucky, Maryland, Michigan, Minnesota, Nevada, New Mexico, New York, North Carolina, Oregon, Puerto Rico, South Carolina, Tennessee, Utah, Vermont, Virginia, the Virgin Islands, Washington, and Wyoming. (In Connecticut and New York, the plan covers only State and local government employees.)

II. Pertinent Legal Authority

The primary purpose of the Occupational Safety and Health Act (29 U.S.C. 651 *et seq.*) (The Act) is to assure, so far as possible safe and healthful working conditions for every American worker over the period of his or her working lifetime. One means prescribed by the Congress to achieve this goal is the mandate given to and the concomitant authority vested in, the Secretary of Labor to set mandatory safety and health standards. The Congress specifically mandated that:

> The Secretary, in promulgating standards dealing with toxic materials or harmful physical agents under this subsection, shall set the standards which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life. Development of standards under this section shall be based upon research, demonstrations, experiments, and such other information as may be appropriate. In addition to the attainment of the highest degree of health and safety protection for the employee, other considerations shall be the latest available scientific data in the field, the feasibility of standards, and experience gained under this and other health and safety laws. (Section 6(b)(5)).

Where appropriate, OSHA standards are required to include provisions for labels or other appropriate forms of warning to apprise employees of hazards, suitable protective equipment, exposure control procedures, monitoring and measuring of employee exposure, employee access to the results of monitoring, appropriate medical examinations or other tests. These must be available at no cost to the employee (Section 6(b)(7)). Standards may also prescribe recordkeeping requirements where necessary or appropriate for the enforcement of the Act or for developing information regarding occupational accidents and illnesses (Section 8(c)).

Section 3(8) of the Act, 29 U.S.C. 652(8), defines an occupational safety and health standard as follows:

> A standard which requires condition, or the adoption or use of one or more practices, means, methods, operations or processes, reasonably necessary or appropriate to provide a safe or healthful employment and place of employment.

The Supreme Court has said that Section 3(8) must be applied to the issuance of a permanent standard to determine that it is reasonably necessary and appropriate to remedy a significant risk of material health impairment (*Industrial Union Department* v. *American Petroleum Institute*, 448 U.S. 607 (1980)). This "significant risk" determination constitutes a finding that, in the absence of the changes in practices mandated by the standard, the workplaces would be "unsafe" in the sense that workers would be threatened with a significant risk of harm. (Id. at 642).

The court indicated, however, that the significant risk determination is not a "mathematical straitjacket," and that "OSHA is not required to support its finding that significant risk exists with anything approaching certainty." The Court ruled that "a reviewing Court (is) to give OSHA some leeway where its findings must be made on the frontiers of scientific knowledge (and that) * * * the Agency is free to use conservative assumptions in interpreting the data with respect to carcinogens, risking error on the side of over protection rather than under protection" (448 U.S. at 655).

The Court also stated that "while the Agency must support its finding that a certain level of risk exists with substantial evidence, we recognize that its determination that a particular level of risk is 'significant' will be based

largely on policy considerations" (488 U.S. at 655, n.62). It is in the Agency's burden to make this showing, based on substantial evidence that it is at least more likely than not that such a substantial risk exists.

After OSHA has determined that significant risk exists and that such risk can be reduced or eliminated by the proposed standard, it must set the standard "which most adequately assures, to the extent feasible on the basis of the best available evidence, that no employees will suffer material impairment of health" (section 6(b)(5) of the Act). The Supreme Court has interpreted this section to mean that when adopted an OSHA standard must be the most protective possible to eliminate significant impairment of health, subject to the constraints of technological and economic feasibility (*American Textile Manufacturers Institute, Inc.* v. *Donovan*, 452 U.S. 490 (1981)).

In addition, section 4(b)(2) of the Act provides that OSHA's general industry standards would apply to construction and other workplaces where the Assistant Secretary has determined those standards are more effective than the standard which would otherwise apply.

In this document, OSHA is amending the revised standards for Asbestos (29 CFR 1910.1001 and 1926.58) to remove nonasbestiform ATA from their scope. The basis for this decision is the Agency's determination that the available evidence is insufficient to conclude that nonasbestiform ATA present the same type or magnitude of health effect as asbestos.

The inclusion of the nonasbestiform minerals under the 1972 standard was based on the Agency's view that nonasbestiform ATA likely subjected exposed employees to a significant risk of asbestos related disease and in the same way as asbestos. Additional evidence and evaluations which have been submitted to OSHA led to a reassessment of OSHA's views.

The Supreme Court in *Motor Vehicle Manufacturers Association* v. *State Farm Mutual Automobile Insurance Co.* (State Farm), (463 U.S. 29, 1983) held that "an Agency changing its course by rescinding a rule is obligated to supply a reasoned analysis for the change beyond that which may be required when an agency does not act in the first instance * * *" 463 U.S. at 42. OSHA has previously stated the approach it will follow in raising or eliminating exposure limits in two places. Those are in its reconsideration for the exposure to cotton dust in the nontextile sector at 50 FR 51132–3, October 12, 1985 and in its Air Contaminants Final Rule (54 FR 2698), January 19, 1989.

The evidence must indicate that significant risk is unlikely to exist as a result of the change in the regulation. OSHA's final action in this rulemaking is based on the direction of the Supreme Court in State Farm and is consistent with OSHA's previous approach.

Also, the Supreme Court in its State Farm decision held that recision of a rule is arbitrary if, inter alia the Agency does not consider an important aspect of the problem (463 U.S. at 43). The Court held that an essential component of reasoned decisionmaking requires discussing why alternative ways of achieving the objectives of the Act cannot be adopted. OSHA believes that here it must consider such regulatory alternatives presented by its review of the record, or which are suggested by participants who show the significant benefit and feasibility of such recommendations.

Significance of Risk for Nonasbestiform-ATA

OSHA is empowered to regulate exposure to toxic substances where substantial evidence shows the existence of a significant risk of material impairment. For asbestos, OSHA has found that a lifetime excess cancer risk of 6.7 per thousand and a lifetime asbestosis risk of 5 cases per thousand are correlated with asbestos exposure at the 1986 time-weighted average PEL of 0.2 f/cc and that a still significant risk exists at that level.

OSHA's 1986 risk assessment for asbestos, which was upheld by the United States Court of Appeals for the District of Columbia Circuit, was based on the results of a large number of epidemiologic studies which evaluated human cohorts which were undisputedly exposed to asbestos. For lung cancer, OSHA looked at eight studies which contained good data for the calculation of the dose-response relationship for lung cancer, and six studies to calculate the dose-response relationship for mesothelioma OSHA's evaluation of these studies indicated that the potency coefficients of lung cancer appeared lower where airborne fibers are relatively coarse, than in certain manufacturing operations where the fibers are fine (See 51 FR at 22623).

OSHA did not use the results of any study involving worker exposure to nonasbestiform ATA in its asbestos risk assessment. In determining to include ATA in its 1986 asbestos standards the Agency reasoned that the chemical and structural similarities in varieties of the same minerals allowed a presumption of similar risk, so long as OSHA's fiber definition corresponded to dimensions likely to be carcinogenic. Confirming evidence of similar risk consisted of epidemiologic studies of tremolitic talc miners which showed excess lung cancer and other asbestos related disease. However, at the time, OSHA acknowledged that the studies, although showing positive results, were inconclusive in that the studies did not prove a causal relationship between the mineral exposure and cancer (51 FR 22631).

Thus, the primary basis for including the nonasbestiform varieties of ATA in OSHA's asbestos standards was the Agency's belief that fiber populations with similar "index" fiber counts, presented essentially the same risk, regardless of whether those "index" fibers were strictly asbestos in the mineralogical sense. Dimensions of the "index" fiber in the asbestos standards was a length of at least 5 micrometers with a 3:1 or greater aspect ratio. OSHA believed that the primary determinant of biological activity of asbestos is fiber dimension, and that varieties of asbestos minerals of relevant dimension have the same carcinogenic and fibrogenic potential per fiber. (See 51 FR at 22638).

This determination was the practical equivalent of a qualitative risk assessment for ATA. Given the chemical and structural similarities between nonasbestiform and asbestiform ATA, OSHA determined that similar regulation of both varieties was warranted, so long as dimensionally appropriate fibers were counted.

This decision squarely fit OSHA's mainstream authority to regulate less known substances based on extrapolation from evidence of known related carcinogens. OSHA believed that the Agency was not required to demonstrate the toxicity of each chemical it seeks to regulate through studies demonstrating a clear line of causation. (See *Environmental Defense Fund* v. *E.P.A.*, 598 F.2d 62(C.A.D.C. 1978). OSHA's decision to regulate like asbestos the closely related non-asbestiform varieties of three asbestos minerals was not the first time that OSHA or other regulatory agencies had regulated closely related substances based primarily on evidence relating to the more known variant. In its arsenic standard OSHA had treated pentavalent arsenic as presenting the same health risk as trivalent arsenic, which was conclusively carcinogenic. OSHA based its decision on evidence consisting of studies which demonstrated positive mutagenic and genetic effects by both

trivalent and pentavalent varieties and two positive epidemiologic studies of pentavalent arsenic. A negative study of pentavalent arsenic was rejected by OSHA for problematic exposure description and small numbers of workers studied. OSHA determined that substantial evidence existed to consider both forms of arsenic carcinogenic, and regulated them under the same standard. (43 FR 19584.) This was upheld in *ASARCO* v. *OSHA*, 746 F2d. 483, (4th Circuit, 1984).

Similarly, EPA has regulated less chlorinated PCBs as carcinogens based on extrapolations from data concerning more chlorinated PCBs, which undisputedly showed carcinogenicity. Confirming evidence consisted of some positive in vivo and in vitro tests for the less chlorinated variety. (*EDF* v. *EPA*, supra).

Thus, OSHA and other agencies have based risk assessments for one substance on the quantitative data relating to a related substance if substantial data in the record support the equivalency of risk in a qualitative way, even though dose-response data allowing a separate risk assessment are not available. For example, in the PCB case, positive *in vivo* and *in vitro* studies showed excess risk of about the same magnitude. In the arsenic case, positive epidemiologic and animal data of the less studied substance, corresponded to risk estimates for the more studied variant. Further in both cases, the biological relationship was based on the same factors as the assumed toxic mechanisms.

In this rulemaking, OSHA has reopened the issue of whether nonasbestiform ATA should be regulated like asbestos based on its similarity to the known carcinogen. The evidence submitted to this record includes, in the Agency's view, virtually all relevant data and comment existing on this issue, much of which was not previously considered by the Agency. OSHA has examined this record to evaluate whether the risk of the nonasbestiform varieties of ATA can be derived by analogy to asbestos. After a review of this greatly enhanced record, OSHA has reversed its decision of 1986, and determined that there is insufficient evidence to regulate nonasbestiform ATA primarily by extrapolation from data relating to asbestos. Reliable confirming evidence is lacking; animal experimental evidence either shows no or greatly reduced effect for nonasbestiform ATA, epidemiologic evidence relating to nonasbestiform ATA is inconclusive and/or flawed, and dimensional hypotheses of carcinogenicity appear to offer only partial explanations, and in any event are too imprecise for regulatory use. Thus, the record does not contain substantial evidence to support a determination that nonasbestiform ATA presents a health risk similar to asbestos, based primarily on extrapolation from evidence relating to asbestos.

As further discussed in the Health Effects section, below, OSHA has also determined that substantial evidence is lacking in this record to support the regulation of nonasbestiform ATA in the asbestos standards or in a separate health standard based on a separate risk assessment which shows that these mineral forms present the same kind and extent of risk as asbestos, or a lesser but still significant risk to exposed employees greater than the risk caused by particulates not otherwise regulated.

III. Regulatory History

OSHA first regulated asbestos in 1971 when, under authority of section 6(a) of the Occupational Safety and Health Act, it adopted the existing Federal standard for asbestos under the Walsh-Healey Public Contracts Act (29 CFR 1910.93, Table G–3 (36 FR 10466, May 29, 1971). The standard consisted of a permissible exposure limit listed in Table G–3 "Mine Dusts". The Walsh-Healey standard for tremolite was also adopted and separately listed in Table G–3.

Following an emergency temporary standard (ETS) for exposure to "asbestos dust" in 1971 (36 FR 23207, December 7, 1971), OSHA conducted rulemaking and issued a permanent standard under section 6(b) of the OSH Act, which regulated occupational exposure to asbestos. The standard defined asbestos as chrysotile, crocidolite, amosite, tremolite, anthophyllite, and actinolite (29 CFR 1910.93a (later renumbered as § 1910.1001); 37 FR 11318, June 7, 1972). The 1972 standard regulated only fibers longer than 5 micrometers, measured by phase contrast illumination (37 FR 11318, 29 CFR 1910.1001 (1985)). Also at that time, OSHA deleted the entry for tremolite in Table G–3.

On October 18, 1972, OSHA made clarifying revisions to Table G–3. The existing permissible exposure limit for "talc" was explained to apply only to "non-asbestos form" talc, while new entries for "fibrous talc" and tremolite instructed readers to use the permissible limit for asbestos (37 FR 22102, 22142).

All major provisions of the standard which were initially challenged were upheld by the U.S. Court of Appeals for the District of Columbia Circuit in *Industrial Union Department, AFL–CIO* v. *Hodgson*, 499 F.2d 467 (1974).

Because the 1972 standard did not distinguish between asbestiform and nonasbestiform ATA, OSHA began to inspect employers whose employees were exposed to either mineralogic variety.

One supplier of industrial talc containing non-asbestiform anthophyllite and tremolite (the R.T. Vanderbilt Company) petitioned OSHA to restrict the application of the 1972 standard so that nonasbestiform anthophyllite and tremolite would not be covered by it. In October 1974 OSHA interpreted the applicability of the asbestos standard to mean only asbestiform termolite with and aspect ratio of 5 to 1 (Letter from OSHA Assistant Secretary John Stender to R.T. Vanderbilt Company, August 6, 1974; OSHA Field Information Memorandum (FIM) # 74–92, Novermber 21, 1974 (Ex. 411)). However, because of preliminary information received from NIOSH regarding medical evaluations of workers exposed to tremolitic talc, FIM # 74–92 was canceled on January 4, 1977 (Ex. 412). OSHA reverted to its regulatory definition of asbestos, which included all termolite fibers, whether asbestiform or nonasbestiform.

In 1975 OSHA proposed to reduce the PEL and otherwise revise and tighten the asbestos standard to protect employees against carcinogenic effects of asbestos (40 FR 47652, October 9, 1975). No change was proposed concerning the six minerals defined as asbestos, but OSHA proposed to define "asbestos fiber" as a "particulate" instead of a "fiber" so as to stress its "morphology and toxicity * * * rather than its geologic or mineralogic origin." (40 FR 46758). It also proposed to add a three to one aspect ratio and a five micrometer maximum diameter to the definition of fiber in recognition of fiber respirability and the ACGIH recommended methods for fiber sampling and counting using phase contrast microscopy. No hearings were held on this proposal.

In 1983 OSHA issued an Emergency Temporary Standard (ETS) for asbestos, lowering the permissible exposure limit from 2 fibers per cubic centimeter (2 f/cc) to 0.5 f/cc (48 FR 51086, November 4, 1983). In the preamble to the ETS, which also constituted a proposal for a revised permanent standard, OSHA raised the possibility of revising the definition of "asbestos" and "asbestos fiber" and included an extensive discussion of the relative carcinogenicity and toxicity of different fibers (48 FR 51110–51121). As with the 1972 standard, OSHA

concluded there was no basis to regulate fiber types differently (48 FR 51110). The ETS itself was vacated by the Fifth Circuit Court of Appeals on March 7, 1984 for reasons not related to the issue of the mineralogical definition of asbestos.

In its supplemental proposed rule (49 FR 11416, April 10, 1984), OSHA said it was considering a revision of its definition of asbestos to conform to the practice of other federal agencies (the Mine Safety and Health Administration, the Consumer Product Safety Commission, the Environmental Protection Agency, and the Department of Education) which regulated only mineralogically correct "asbestos". The definition under consideration would include only the asbestiform varieties of the six covered minerals. However, OSHA noted that health evidence existed implicating nonasbestiform minerals in the production of asbestos-related disease; that morphology may be a significant causative factor; and that the Agency would examine all relevant evidence before its final decision on coverage (51 FR 14122).

Several parties addressed the issue in written comments and in oral testimony during the rulemaking. A primary proponent of including only a "mineralogically correct" definition of asbestos was the R.T. Vanderbilt Company, a miner and producer of tremolitic talc (See generally Ex. 337). Vanderbilt claimed that health studies at its mine and mill do not show the presence of asbestos-related disease; and that therefore its products should not be regulated with the same stringency as asbestos. Other participants also supported limiting coverage to "mineralogically" defined asbestos (See e.g. 90–3 and 90–143).

Other commentors opposed excluding nonasbestiform tremolite, anthophyllite, and actinolite from the scope of the standard. Public Citizen Health Research Group (Ex. 122; Tr. June 22, pp. 51–52) and the United Brotherhood of Carpenters and Joiners of America (Tr. June 28, pp. 168–172) contended that a revised asbestos standard should include these minerals because of their asbestos-like health effects. Their comments in part were based on findings of the NIOSH studies of upstate New York talc miners and millers, working at Vanderbilt which found an excess of respiratory disease.

OSHA's final standards (29 CFR 1910.1001 and 1926.58) define "asbestos" as "chrysotile, amosite, crocidolite, tremolite asbestos, anthophyllite asbestos, actinolite asbestos, and any of these materials that has been chemically treated or altered" (29 CFR 1910.1001(b); 29 CFR 1926.58(b)). However, these standards also regulate the nonasbestiform varieties of tremolite, anthophyllite, and actinolite. Only "fibers" of these materials are regulated; fibers are defined as particles of the covered materials which are five micrometers or longer with an aspect ratio of at least 3 to 1. These nonasbestiform "fibers" were regulated because OSHA determined that there was substantial evidence to support protection under the revised asbestos standards for workers exposed to nonasbestiform tremolite, anthophyllite and actinolite (51 FR 22631). OSHA, however, did not separately analyze the economic and technological feasibility of the revised provisions in industries using the nonasbestiform minerals.

Following issuance of the standards, a number of parties filed petitions in the Second, Fifth, and District of Columbia Circuit Courts of Appeals for review of the standards under section 6(f) of the OSH Act based on broad challenges to the standard's validity. On June 20, 1986, the R.T. Vanderbilt Company requested an administrative stay of the standard pending judicial review based on its claim that OSHA improperly included nonasbestiform minerals (Ex. 403). This request was denied on July 9, 1986 in a letter from OSHA Assistant Secretary John Pendergrass (Ex. 404). Vanderbilt also filed a stay motion in the United States Court of Appeals for the Second Circuit (Ex. 502). The National Stone Association (NSA) and Vulcan Materials Company, nonparticipants in the rulemaking, also requested a stay of the standards on July 11, 1986 insofar as they applied to tremolite and actinolite exposure from the use of crushed stone in construction (Ex. 406 & 407). In their request for a stay, the NSA claimed that the technological and economic impacts of the new standard on users of crushed stone in the construction industry was never considered in the rulemaking. It alleged severe adverse impacts on the industry and the public as the result of applying the new standard to crushed stone.

Vanderbilt requested OSHA to reconsider its denial of an administrative stay on July 24, 1986 (Ex. 416). Court papers filed by Vanderbilt brought to OSHA's attention internal memoranda from three NIOSH scientists which disputed OSHA's regulatory treatment of nonasbestiform tremolite, anthophyllite and actinolite. Dr. Donald Millar, the Director of NIOSH, wrote to OSHA on July 17, 1986 to reaffirm NIOSH's support for OSHA's positions in the final standards (Ex. 408). On July 18, 1986, OSHA granted a temporary stay insofar as the standards applied to nonasbestiform tremolite, anthophyllite and actinolite (51 FR 37002). OSHA said it was granting the stay in part to enable the agency to review Dr. Millar's letter, the NIOSH memoranda, the submissions of Vanderbilt and various trade associations, and to conduct supplemental rulemaking on whether nonasbestiform tremolite, anthophyllite and actinolite should be regulated in the same manner as asbestos and the feasibility of regulating the affected industries. The stay was extended to July 21, 1988 (52 FR 15722) and thereafter (53 FR 27345), (54 FR 30704) and (56 FR 43699) in order to complete rulemaking. The current stay expires May 30, 1992.

Pursuant to the stay and its extension, the standard, covering tremolite, anthophyllite, and actinolite were to remain in effect as they had applied to minerals under the previous standard. The 1972 standard was republished as 29 CFR 1910.1101 (1987).

On February 12, 1990 OSHA published a Notice of Proposed Rulemaking (NPRM) in which the Agency proposed to remove nonasbestiform tremolite, anthophyllite and actinolite from the scope of the revised standards for Asbestos. At that time OSHA also presented and requested comment on various alternatives for regulating nonasbestiform ATA.

Public hearings on the proposed standard were held in Washington, DC May 8–14, 1990, to provide interested parties and the public with the opportunity to comment on the proposed action. Post hearing submissions of data, comments, and briefs were received through July 23, 1990.

After the close of the post hearing briefing comment periods, the American Thoracic Society (ATS) submitted a report to the record concerning the health risks of nonasbestiform tremolite (Ex. 525). The Agency set an additional period, later extended to December 14, 1990 to enable the public to submit written comments and analyses on all issues raised by the ATS report. In order to review comments on this document, as well as the entire rulemaking record, the Administration Stay was extended to February 28, 1992 (56 FR 43699) and again to May 30, 1992 (57 FR 7877).

The record of the public hearing contains the original transcript of the hearing, which incorporated the record as a whole and exhibit numbers 505 to 553. Copies of the materials contained in the record may be obtained from the OSHA Docket Office, room N–2625, U.S. Department of Labor, 200 Constitution Avenue NW., Washington, DC 20210. The Docket Office is open to the public

from 10 a.m. to 4 p.m. Monday through Friday except Federal Holidays.

The final decision on the occupational exposure to nonasbestiform ATA is based on full consideration of the entire record of this proceeding, including material discussed or relied upon in the proposal, the record of the informal hearing, and all comments and exhibits received.

IV. Mineralogical Considerations

The following is a discussion of the mineralogical evidence submitted to this record concerning defining and differentiating the types of minerals commonly designated as "asbestos", "asbestiform" and "nonasbestiform". OSHA's position, expressed in the proposal and in the 1986 standards, was that precise mineralogic definitions are helpful in describing the scope of the standard, but absent strong evidence that mineralogic distinctions are biologically relevant, such distinctions by themselves, should not dictate regulatory health based decisions. In the 1986 standards, OSHA defined "asbestos" and "nonasbestiform ATA" separately, but covered both varieties based on health effects evidence.

Much evidence and testimony in this proceeding related to the extent to which different mineral varieties can be distinguished. OSHA's overall regulatory approach to this issue is shaped by its mandate to protect employee health, and to err on the side of protection when presented with a close scientific question. The Agency believes that mere difficulties in differentiating between these mineral varieties should not dictate uniform regulatory treatment, unless such difficulties reflect the fact that the varieties, in biologically relevant respects, behave the same. Of course, misidentification of mineral type affects the confidence in and usefulness of studies reporting the biological potential of different mineral types. Also, the extent of analytical difficulty in distinguishing even well characterized mineral types, would be relevant to OSHA in making feasibility determinations concerning analytic methods.

In general there was agreement concerning the broad definitions of these mineral classifications. Thus, asbestos is not a precisely defined chemical compound, but rather, a collective term given to a group of similar silicate minerals having commercial significance. Historically six silicate minerals have made up the group of minerals which has been collectively referred to as Asbestos. These six minerals are chrysotile, crocidolite, amosite (which is mineralogically known as cummingtonite-grunerite asbestos), tremolite asbestos, anthophyllite asbestos, and actinolite asbestos. Chrysotile belongs to the family of minerals called serpentine minerals. The remaining five minerals belong to the family of minerals called amphiboles.

Dr. Arthur Langer pointed out in his testimony and comments to OSHA, that the definition of asbestos is comprised of a mineralogical definition and an economic geology definition. Langer states:

> Asbestos is described in the mineralogical literature as several silicate minerals with the following characteristics: Minerals occurring in nature as fibers; Fibers are bundles composed of "hair-like" (filiform) fibrils, each with a high length-to-width ratio; Fiber bundles are polyfilamentous and the fibril strands may be easily separated by hand. Unit fibrils cannot be resolved by [the] unaided eye; In addition to the mineralogical criteria, the economic geology literature contains additional descriptive terms, mostly pertaining to properties exhibited by asbestos which render it useful in commerce. Among these are: fibers exhibit stability in acids and alkalies; act as electrical insulators; act as thermal insulators; fibers are highly flexible and can be woven into asbestos cloth or rope; fibers possess diameter dependent high tensile strength. Together, both geological disciplines have defined what asbestos is mineralogically. (Ex. 517, Tab 5)

Dr. Ann Wylie, testified that "Asbestos is a commercial term applied to a group of highly fibrous silicate minerals that readily separate into long, thin, strong fibers of sufficient flexibility to be woven, are heat resistant and chemically inert, and possess a high electical insulation and therefore are suitable for uses where incombustible, nonconducting, or chemically resistant material is required." (Ex. 479–23).

Similarly, the Bureau of Mines stated in comments to the NPRM that a correct mineralogical definition of asbestos was:

> A term applied to six naturally occurring serpentine- and amphibole- group minerals that are exploited commercially because they crystallize into long, thin, flexible fibers that are easily separable when crushed or processed, can be woven, are resistant to heat and chemical attack, and are good electrical insulators. The six serpentine- and amphibole-group minerals commonly referred to as asbestos are chrysotile, cummingtonite-grunerite asbestos (amosite), riebeckite asbestos (crocidolite), anthophyllite asbestos, tremolite asbestos, and actinolite asbestos (Ex. 478–6).

The above minerals which are collectively termed asbestos, are also described as being asbestiform. Asbestiform is a mineralogical term describing a particular mineral habit. The habit of a mineral is the shape or form a crystal or aggregate of crystals take on during crystallization and is dependent on the existing environmental/geological conditions at the time of formation. The National Stone Association (NSA) and the American Mining Congress (AMC) state that, "The asbestiform habit can be defined as a habit where mineral crystals grow in a single dimension, in a straight line until they form long, thread-like fibers with aspect ratios of 20:1 to 100:1 and higher. When pressure is applied, the fibers do not shatter but simply bend much like a wire. Fibrils of a smaller diameter are produced as bundles of fibers are pulled apart. This bundling effect is referred to as polyfilamentous." (Ex. 467) Dr. Wylie testified that the asbestiform habit can be recognized by certain characteristics using light microscopy. For example she testified that:

> Populations of asbestiform fibers, and this would include all, not just commercial asbestos, but all asbestiform fibers that I have looked at, they have mean aspect ratios greater than twenty to one for particles longer than five microns—and again, it's very important that we qualify, when speaking of aspect ratio, length, because aspect ratio by itself as a population characteristic has no meaning—very thin fibrils that are usually less than half a micrometer in width. And you will see in any population of asbestiform fiber[s] at least two of the following characteristics. Normally they are all present, but two, I think is enough to convince me. Parallel fibers occurring in bundles, fibers displaying splayed ends, the matted masses of individual fibers, and fibers showing curvature. (Tr. 5/9, p. 92)

However Dr. Wylie emphasized that these are characteristics which apply to populations of asbestiform fibers and not a particular particle. She states that "The characteristics that were listed were population characteristics, not characteristics on a fiber by fiber discriminator. They weren't meant to say a particular particle must meet all these criteria in order to say that this is an asbestos particle or population present. And that's the way that definition is approached that if we have a bulk sample, and we are looking in that sample for the presence of—asbestos," (Tr. 5/8, p. 144)

In further clarification of the asbestiform habit Dr. Tibor Zoltai, a professor of mineralogy at the University of Minnesota, states that:

> The development of the asbestiform properties is a gradual process, (and) depends on the extent of the appropriate conditions of crystallization. Consequently, there are variable qualities of asbestiform fibers. The poor quality asbestiform fibers of

amphiboles are called byssolite or brittle asbestos. The high quality asbestiform fibers because of their highly developed flexibility, strength and physical-chemical durability, constitute desirable industrial materials and are exploited under the generic term of asbestos. Although practically all amphiboles and most other minerals are known to occur in asbestiform habit, only a few amphiboles are known in sufficient concentration and quantity to produce commercial asbestos: * * * (Ex. 548).

Thus, asbestos is a collective term composed of both mineralogical and economic elements which has been used to refer to a specific set of asbestiform minerals which are, or were in the past, regarded as being commercially significant. The term asbestiform is a mineralogical term used to refer to those minerals which are found in a particular mineral habit. That is, while all asbestos is asbestiform, not all asbestiform minerals are asbestos.

As the above discussion shows, the term "asbestos" is based on more than mineralogic criteria, and its meaning also reflects to a certain extent the interests of the affected commercial communities. Nonasbestiform mineral varieties have a different commercial history. For the most part, they have had little commercial significance. This is related to their different crystallization habit. Because, unlike asbestos, they do not grow unidirectionally, into long thin fibers, therefore they often do not possess properties such as wearibility or high tensile strength which make them valuable for asbestos-like uses. For the most part nonasbestiform minerals are not mined for any special property, but rather, they are mined generally with other minerals as a basic stone product. However, nonasbestiform tremolite when mined with talc, results in enhanced usefulness to industries such as ceramic manufacturing, because of the other properties specific to nonasbestiform minerals.

The record makes clear, that from a mineralogic perspective the crystallization growth pattern of these minerals determines whether they develop as asbestos, or as nonasbestiform varieties. In joint comments to the record, the NSA and the AMC stated that "in the nonasbestiform variety crystal growth is random, forming multi-dimensional prismatic patterns. When pressure is applied, the crystal fractures easily, fragmenting into prismatic particles. Some of the particles or cleavage fragments are acicular or needle-shaped as a result of the tendency of amphibole minerals to cleave along two dimensions but not the third" (Ex. 487).

In his comments to the record, Dr. Zoltai notes that: Both asbestiform and nonasbestiform amphibole minerals have the same chemical composition and crystal structure. They are not distinguishable by instrumental analysis and x-ray diffraction. The difference between them is in their respective crystallization habit, that is, in their respective condition of crystallization. Nonasbestiform prismatic crystals are the common crystal habits of amphiboles. The asbestiform crystallization habit is the unusual one, it requires unique temperature and pressure conditions inducing unidirectional and rapid crystal growth. (Ex. 446)

In the NPRM, OSHA stated that unlike asbestiform minerals, nonasbestiform minerals do not separate into fibrils but, during processes such as mining, milling and/or processing can be broken down into fragments resulting from cleavage along the minerals two or three dimensional plane of growth. OSHA also stated that particles thus formed, are generally referred to as cleavage fragments and these fragments may occur in dimensions equal to asbestiform fibers.

Various commentors agreed with OSHA's definition of a cleavage fragment but objected to OSHA's characterization that nonasbestiform cleavage fragments and asbestiform fibers occur in similar dimensions. In testimony to OSHA, Kelly Bailey, an Industrial Hygienist with Vulcan Chemical Company speaking for the NSA stated:

The NSA believes that this statement is deliberately misleading in that it fails to take into account the population characteristics of both cleavage fragments and asbestiform fibers. It is true that there are some cleavage fragments that may have dimensions of 10:1, 20:1 or higher in aspect ratio when examined with PCM and that there may be a few asbestos fibers that have low aspect ratio dimensions similar to cleavage fragments; however, to imply that cleavage fragments do not differ from asbestiform fibers in an observable, dimensional way is poppycock! (Ex. 479-23).

Similarly, in earlier testimony to OSHA during the rulemaking for the 1986 revised standards, Dr. Wylie stated:

A particle of any mineral which is formed by regular breakage is called a cleavage fragment. Mineralogically, a fiber or fibril is a crystal which has attained its shape through growth, in contrast to a cleavage fragment which has attained its shape through regular breakage. The shape of amphibole cleavage fragments is somewhat variable depending upon the history of the mineral sample. Some amphiboles when crushed will produce a population of particles which may have the average aspect ratio of 5 to 1 or 6 to 1, whereas other amphibole samples when crushed may produce a population of particles whose aspect ratios average closer to 8 to 1 or 10 to 1. And in almost any population of amphibole cleavage fragments, it is possible to find a few particles whose aspect ratios may extend up to 20 to 1 or perhaps even higher. Amphibole asbestos populations, on the other hand, are characterized by aspect ratios which are considerably greater than this." (Ex. 230, Docket # H-033c).

Dr. Ann Wylie reiterated her earlier opinions in the current rulemaking stating:

Throughout OSHA's Notice of Proposed Rulemaking, they imply that cleavage fragments are similar in size to asbestos fibers, and the distinctions between them are fuzzy. In most cases, this is simply not so. Asbestos crystallizes from a fluid medium: growth takes place rapidly in one direction; the chemical makeup of the fluid may inhibit growth laterally. * * * These fibrils are single or twin crystals and they have very, very narrow widths and long lengths. It is the narrow width and long lengths that give asbestos flexibility and high tensile strength. Fibrils share a common axis of growth, but they are randomly [ar]ranged in the direction perpendicular to the fiber axis, and when disturbed, they are easily desegregated. Because their origin is different, population of cleavage fragments and fibers of the same minerals are simply different. Dr. Wylie adds that: While there may be some cleavage fragments that cannot be distinguished from asbestos solely on dimensions, and there are some particles in asbestos samples that can't be distinguished from cleavage fragments, the populations are as wholes easily distinguishable. (Tr. 5/9, pp. 102-103)

As evidence of these differences Dr. Wylie cited to her paper entitled "An Analysis of the Aspect Ratio Criterion for Fiber Counting". Dr. Wylie testified:

As a part of the record, I have prepared a paper entitled "An Analysis of the Aspect Ratio Criterion for Fiber Counting; and that is part of OSHA's record. The paper reviews the distribution of aspect ratio for fiber and fiber bundles of amosite, crocidolite, chrysotile, and they clearly show that for those fibers and fiber bundles, again, that are longer than five micrometers, 100 percent or close to it, have aspect ratios greater than ten to one, and in every population that I have ever looked at that has the asbestiform habit, more than 50 percent have aspect ratios in excess of twenty to one * * * but most of them are 90 percent.

Also included in that paper are data from bulk and airborne samples of cleavage fragments, and there are cleavage fragments [with] aspect ratios greater than ten to one, and there are some that have aspect ratio[s] greater than twenty to one, but they are in much lower abundance, as a population. (Tr. 5/9, pp. 94-95).

While Dr. Wylie notes that there are differences in the distribution of aspect ratios when one looks at populations of asbestos fibers and nonasbestiform cleavage fragments, she also states that

"aspect ratio is a dimensionless parameter" and "* * * it lacks information about the size particles; it only describes shape." (Tr. 5/9, p. 95). Rather than aspect ratio, Dr. Wylie stressed that "width is a much more fundamental parameter of asbestos fibers, and perhaps will shed some light on how we tell particles that are elongated, whether they are cleavage fragments, or whether they are asbestos." (Tr. 5/9, p. 95).

To illustrate this point Dr. Wylie presented data in her testimony on the widths of various populations of asbestos fibers and nonasbestiform cleavage fragments from both bulk and airborne data (Transcripts, May 9, pp. 2-95 to 2-98). This data showed that in the populations of asbestos fibers she studied, the majority of fibers had widths less than one micrometer. For example, 85-90% of the crocidolite fibers she studied had widths less than one micrometer and 60% had widths less than 0.5 micrometers. In amosite samples, greater than 90% had widths less than one micrometer and 75% had widths less than 0.5 micrometers. In tremolite asbestos samples, 85-95% of the fibers had widths less than one micrometer and 75% had widths less than 0.5 micrometers. Wylie stated that when looking at these fiber populations "* * * it really doesn't make any difference, much, whether you look at particles longer than five micrometers, or all particles in a population, when you look at width. Because of the nature of asbestos, width changes very little as length increases, * * *" (Transcripts May 9, p. 2-96). Dr. Wylie acknowledged, however, that asbestos fiber bundles may have widths greater than one micrometer, but she added that even in these cases the majority of particles are less than one micrometer.

Dr. Wylie was criticized for inconsistencies in her comparative population: i.e., sometimes using all fibers, other times citing only those exceeding certain dimensions, e.g. longer than 5 micrometers. Dr. Wylie agreed that, "depending upon which of those qualifiers you put forth, you get vastly different datasets. Now, I took all my cleavage fragment data and I first looked at the particles that are longer than five micrometers, and of these—I'm just going to use a ten to one as aspect ratio—11 percent have aspect ratios greater than ten to one. If we look at that dataset * * * and only at the particles that have aspect ratios greater than three to one * * * and are longer than five micrometers, then we would say its six percent are longer than five micrometers and have aspect ratios greater than ten to one. And finally if we look at particles that are both longer than five micrometers, and have an aspect ratio greater than three to one, we have 19 percent with aspect ratios greater than ten to one." (Tr. 5/9 at 106-107).

The record contains some additional, but less comprehensive evidence on comparative dimensions of nonasbestiform cleavage fragments and their asbestiform analogues. For example, in 1979, the Bureau of Mines compared 8 samples of ground tremolite of varying habit. It concluded that "based on this limited study, there is a relationship between the number of particles of 'critical' dimensions, >10 μm in length and <0.5 μm in width, and the habit of the tremolite-actinolite prior to grinding. * * * Only the asbestos variety gave long, thin particles of the dimensions established by some medical scientists as necessary to produce adverse biological effects in laboratory animals." (See RI 8367, p. 17 as part of the NIOSH pre hearing submission Ex. 478-15)

A critical dimensional distinction between asbestiform fibers and ATA appears to be their widths. Thus, Dr. Wylie stated that her analyses of width show that "About 80 percent of the amphibole cleavage fragments longer than five micrometers, have widths greater than one micron, and none have widths less than 0.25." (Tr. 5/9, p. 98)

Dr. Wylie also pointed out how the width of asbestos fibers will influence their aspect ratio. She states that "the mean width of asbestos fibers is less than half a micron, and if you have five micrometer particles, you have to have an aspect ratio of at least 10 to 1." (Tr. 5/9, p. 101-102). Moreover in her comments to NPRM she states that "while low aspect ratio fiber (or fiber bundles) are present in asbestos populations, they are characteristic of short asbestos fibers * * *. Since the mean width of asbestos fibers is less than 0.5 micrometers, the mean aspect ratio of a 5 micrometer fiber is about 10:1." (Ex. 479-23).

Dr. R.J. Lee, a microscopist and mineralogist with R.J. Associates, also noted the importance of width in distinguishing asbestos fibers from nonasbestiform cleavage fragments. Dr. Lee testified the following:

> First asbestos—airborne asbestos is less than one micrometer in diameter, unless it's present as bundles or cluster, which exhibit the characteristic fibrillar structure of asbestos, or as Dr. Wylie indicated, the hallmark of asbestos. Asbestos larger than a half a micron is a bundle—.
>
> Second, nonasbestos particles longer than five micrometers in length are generally [more] than one micrometer in diameter, and only rarely less than half a micrometer in diameter. When larger than one mocrometer in diameter, they do not exhibit the fibrillar structure of asbestos. (Tr. 5/9, pp. 114-115).

Similarly in their joint comments to the record the NSA and the AMC stated the following observations about particle width:

> Due to the straight line fibrillar crystal growth of asbestos, the width of an asbestos fiber is essentially independent of its length and is not easily altered by processing. In contrast, cleavage fragment populations show increasing width as particle length increases due to the characteristics imparted from normal three dimensional crystal growth. The result of this difference is cleavage fragments with widths rarely less than 0.5 micrometer and almost never less than 0.25 micrometer. Asbestos tends to show a high proportion of fibers less than 0.25 micrometer in width. (Ex. 467)

Dr. Charles Spooner, a microscopist and mineralogist with Charles Spooner and Associates Inc., concurred in his testimony that asbestos fibrils have widths less than 1 micrometer and that most cleavage fragments have low aspect ratio (Tr. 5/8, pp. 120-121). However he also noted that cleavage fragments may also have high aspect ratios. Dr. Spooner stated that "In the universe of amphibole cleavage fragments it seems likely that a greater proportion will exist as more or less equant bodies, however, there will be those instances where high aspect ratio respirable cleavage fragments will be generated upon crushing of the amphibole bearing rock." (Ex. 512).

As noted earlier in this discussion, Dr. Wylie acknowledged that one may find a few cleavage fragments with high aspect ratios, but she added that populations of asbestos fibers and cleavage fragments, as a whole, are distinguishable from one another. However, Dr. Spooner points out that "* * * from the industrial hygiene perspective, very often we are dealing with air samples. We are looking at an airborne fiber and trying to assess its respirability. And again, we are often in the industrial hygiene setting, we don't have the opportunity to know where the material is coming from, nor do we have the opportunity to look at a very large population of fibers * * *" (Tr. 5/8, pp. 117-118). Thus OSHA believes that while one can differentiate between mineral types when populations of particles are examined, when single, isolated particles are examined (e.g. particles from air samples) the ability to differentiate may become more difficult.

In the NPRM OSHA stated that at the microscopic level, on a particle by

particle basis, differences in gross growth characteristics may not be readily observable. Similarly, Dr. Art Langer acknowledged that "* * * in some instances single, isolated particles may be impossible to distinguish, i.e. acicular cleavage fragment from asbestiform fibril" (Ex. 517, Tab 5). Dr. Langer also noted however that while there are some particles which defy mineralogical identification, the percentage of particles that comprise this group is a small percentage (Tr. 5/11, p. 230).

Identification of fibers is confounded by the existence of particles which do not fit a precise mineralogic definition. For example, some samples of industrial talc have been shown to contain "intermediate fibers." Dan Crane, a microscopist at OSHA's Salt Lake City Technical Center, describes these intermediate fibers which are found in industrial talc samples and notes that "It is only by a combined optical/electron optical approach can the nature of the intermediate fibers can be determined. Even at that, they defy definite description." (Ex. 410-23). Mr. Crane goes on to explain that:

> When one looks at the industrial talcs in the microscope, he sees large numbers of particles that are much longer than 20 to 1 even to nearly 100 to 1 in aspect ratio. The first reaction is to say these are the asbestos fibers of tremolite and anthophyllite indicated by the known presence of those minerals in the products. Unfortunately, this is a false assumption. They are for the most part fibers of industrial talc. They have been dubbed intermediates by us, as talcboles by Malcom Ross and fibrous biopyriboles by David Veblan. What they are not is anthophyllite or tremolite. (Ex. 410-23)

In his description of these intermediate fibers Crane notes that examining these particles by light microscopy (e.g. using indices of refraction and dispersion oils) one would not call these particles anthophyllite. However, when one uses electron microscopy one would conclude that these particles are indeed anthophyllite. Mr. Crane explains why this difference occurs:

> The fault can be corrected when the analyst realizes that in this particular mineral, the deposit *was* anthophyllite at one time. The particular mechanics of this are beyond the scope of this letter. Suffice it to say that it is being done in such a way as to leave the more major structure of the anthophyllite fibers intact while transforming them to talc. This residual structure has given rise to electron diffraction patterns that mimic amphibole patterns. Very careful measurement and calibration of these patterns reveal subtle strains in the structure leading to a mineral with similar features to talc and to anthophyllite and yet the numbers fall in between. * * * I have described these other fibers because they are the fibers with the closest morphological similarity to asbestos. They do have splintering and bundle of sticks and frayed ends as characteristics. These are characteristics which we often ascribe to truly asbestiform minerals. All the samples we have examined have been crushed prior to our receiving them. Therefore, we cannot say whether they grew in nature as asbestos fibers. They do look like asbestos and if morphology is the major role in toxicity or carcinogenicity these should be considered more important tha[n] the non-fibrous cleavage fragments of tremolite and anthophyllite. (Ex. 410-23)

Dr. Arthur Langer, in his testimony, also discussed the difficulties in identifying these intermediate fibers. He stated that:

> * * * some of us might call this a pyrobole, pyroxene and amphibole. This has also been described in various deposits, and you're going to ask me about the Vanderbilt talc deposit. That's fine because they're intergro[wthes] like this in the Vanderbilt talc deposit. These are the complex fibers that we have talked about that defy mineralogical classification. (Ex. Tr. 5/11, pp. 170)

The significance of "intermediate" or "transitional" fibers was also addressed by Dr. Langer, who stated that OSHA's major question should be "how common are they in the work place?" and answered "I don't think they're terribly common in the work place. They are only described in certain specific locales." (Tr. 5/11, p. 219).

OSHA notes that even those mineralogists who contend that asbestos is a separate mineral entity from nonasbestiform ATA, agree that intermediate forms exist. Dr. Tibor Zoltai, Professor of Geology at the University of Minnesota, explained that "* * * (T)he development of asbestiform properties is a gradual process, (and) depends on the extent of the appropriate conditions of crystallization. Consequently, there are variable qualities of asbestiform fibers. The poor quality asbestiform fibers of amphiboles are called byssolite, or brittle asbestos. The high quality asbestiform fibers, because of their highly developed flexibility, strength and physical-chemical durability, constitute desirable industrial materials and are exploited under the generic term of asbestos." (Ex. 546). Dr. Langer testified that based on Dr. Wylie's work, it is known that byssolite is not composed of unit fibrils. "So we would not classify byssolite as an asbestos mineral. Now some people consider this as a transition kind of mineral in characteristics." (Tr 5/11 at 518) Other mineral forms exist which are intermediate between anthophyllite and talc, as discussed above.

In summary, the discussion indicates that populations of fibers and populations of cleavage fragments can be distinguished from one another when viewed as a whole. For example one can look at the distribution of aspect ratios or even widths for a population of particles and can then generally identify that population of particles as being asbestiform or nonasbestiform. However when one looks at individual particles, (e.g. particles from air sampling filters) sometimes these mineralogical distinctions are not clear. Unfortunately the data in the record is insufficient at this time to precisely determine how often these situations occur.

The record also describes the presence of various kinds of "intermediate" fibers, which "defy mineralogic classification". Various participants have requested OSHA to base its regulatory decisions on precise mineralogic definitions. Clearly, any significant presence of mineral types which "defy classification", would defeat such an approach. Although these transitional fibers exist OSHA does not believe that independent evidence of their health effects exists which would support regulation. Dr. Langer testified that there are some fibers which "defy mineralogical identification" but they are a "small percentage" (Tr. 5/11, p. 230). Thus, although their presence lends credence to the explanation that asbestos minerals and nonasbestiform varieties developed on a continuum it does not change the fact that for most mineral deposits, asbestos and nonasbestiform habits are distinguishable.

OSHA finds, based on this record that while these intermediate fibers do exist, the record indicates that they are minor constituents of most mineral deposits. In general, when observed in their natural habit of growth, the two habits of asbestiform and nonasbestiform minerals are distinctly different. The record also indicates that populations of particles derived from mining, crushing or processing these minerals, are also distinctly different (e.g. in the distribution of widths and aspect ratios). However on an individual particle basis, which is often the case for particles from air monitoring samples, these distinctions may become less clear. The record indicates that there are situations where individual particles of

asbestiform and nonasbestiform minerals may be indistinguishable. These situations are likely to be rare in occupational contexts but OSHA has little information upon which to make such a determination.

The regulatory implication of these findings are as follows: Several participants suggested that all forms of asbestos and their nonasbestiform analogues should be treated as a single mineral entity for purposes of regulation because the forms of ATA cannot be distinguished, and there is no clear mineralogic dividing line between various varieties of ATA. Dr. Charles Spooner, a witness for OSHA, a geochemist, a mineralogist and an industrial hygienist, in response to a question concerning how his laboratory distinguishes asbestos from fibers that are not asbestos, stated that "at this point if we identify the mineral tremolite, we make no distinction on the basis of fiber." (Tr. 5/8, p. 119). Dr. Spooner's post-hearing submission again noted that distinguishing asbestiform and non-asbestiform cannot be made reliably either on the basis of a hand sample or microscopic examination: Hand-specimen characterization of mineral habit does not necessarily carry over to mineral habit on the micro scale; and, on the micro scale, high-aspect ratio cleavage fragments and asbestiform fragments can co-exist. Dr. Spooner recommended that "the issue must be resolved on the basis of biological activity and aspect ratio of the respirable fibrous bodies." (Ex. 512).

Dr. Bruce Case, in a letter to the British Journal of Industrial Medicine, November, 1990, provides a clear summary of the mineralogic argument for considering asbestiform ATA and non-equant nonasbestiform ATA to be a single substance for purposes of regulation:

> The major flaw in the substitution of mineralogical definitions for microscopical characteristics is a reliance of the former on gross morphology. For regulatory and health assessment purposes, it is microscopical morphology that counts: there is no evidence that potential-affected cells can distinguish between "asbestiform" and "non-asbestiform" fibers having equivalent dimensions. The lack of agreement as to what is and what is not "asbestiform" tremolite would be less critical if those who advocate such a definition could show that there is a clear line between the two forms when they present 'fibrous' morphology. Unfortunately, this is not the case. Pooley has noted that the differences in structure between massive, acicular and fibrous morphology are not "sharply defined", but rather represent points on a continuum. So-called cleavage fragments may, in a strict morphological sense, be fibrous in their appearance in microscopic fields, and there is no convincing evidence that these 'fibers' are of no public health concern. (Ex. 529.4)

The ATS's report also concluded that mineralogic distinctions between different forms of anthophyllite, actinolite and tremolite were not clear: "It became apparent both from our review of the literature and from submissions made to this committee by experienced mineralogists, that the distinction between cleavage fragment and asbestiform fibers, although theoretically clear, is in practice extremely murky." (Ex. 525 at 3)

As noted above, other participants took issue with these statements. In particular, in a post-hearing submission, the R.T. Vanderbilt Company directly took issue with the ATS statement quoted above as follows: "(a)t the OSHA hearing, Dr. Wylie, Dr. Langer and Mr. Addison explained that the distinctions at issue were in no way 'murky' (theoretically, practically, or otherwise). While we do not disagree that some gray areas exist (i.e., at the single crystal level), the important day-to-day distinctions at issue in this rulemaking simply do not fit this 'murky' characterization". (Ex. 529-6 at 3). Other presenters made similar statements. (See e.g., testimony of Dr. Wylie at Tr. 5/9, at 103 and Dr. Lee at Tr. 5/9, at 1).

OSHA has determined that nonasbestiform ATA and asbestos anthophyllite, actinolite, and tremolite should be defined separately for regulatory purposes to conform to common mineralogic usage. As discussed above, the testimony of Dr. Wylie, Dr. Langer, Dr. Nolan, Dr. Campbell, the Bureau of Mines and others agreed that populations of asbestos and nonasbestiform ATA are separate mineral entities, which for the most part have widely diverging population characteristics which are the result of its habit of crystallization in nature. In addition, these characteristics, such as high fibrosity, fiber shape and size, and easy separability appear to be biologically relevant in producing disease. The agency notes that the position it adopted in the 1986 standards, where it stated: "(t)he Agency recognizes that the minerals tremolite, actinolite and anthophyllite exist in different forms", and therefore required that warning signs and labels for ATA need not include the term "asbestos" (See 51 FR at 22679, 29 CFR 1910.1001 (j)(2)(iii), 1926.58(k)(1)(iii), recognized the mineralogic distinctions, but did not distinguish the minerals based on biologic effects. Thus, the difference between the Agency's 1986 and its current positions is not mineralogical and as explained above, is related to its view of the health effects evidence. Thus although the Agency now reaches a different conclusion than it did in 1986 concerning the evidence of health risks of nonasbestiform ATA, it continues to believe that the mineralogic forms are sufficiently distinctive to be treated differently for regulatory purposes. Also, unlike its determination in 1986, which was based on a far less extensive review of health effects evidence, the Agency now finds that differences in biologic effect between asbestos and its nonasbestiform analogues are likely related to the distinctions which define the two groups as separate mineral entities.

V. Health Effects

In its proposal OSHA reviewed the available health effects evidence and preliminarily concluded that "there are a number of studies which raise serious questions about the potential health hazard from occupational exposures to non-asbestiform tremolite, anthophyllite and actionolite. However, the currently available evidence is not sufficiently adequate for OSHA to conclude that these mineral types pose a health risk similar in magnitude or type to asbestos. The Agency believes, however, that the evidence suggests the existence of a possible carcinogenic hazard and other impairing non-carcinogenic adverse health effects." (55 FR 4943).

After reviewing the rulemaking record compiled subsequent to the publication of the proposal, OSHA reaffirms its view of the health effects evidence. The few new studies that have come to light in this rulemaking are still inconclusive. It should be noted that OSHA believes the health effects evidence falls short regardless of whether this proceeding is viewed as deregulatory or as a regulatory initiative.

More specifically, OSHA believes that the evidence viewed as a whole does not rule out a possible carcinogenic effect of certain subpopulations of nonasbestiform ATA at an unspecified exposure level. However, as discussed below, various uncertainties in the data and a body of data showing no carcinogenic effect, do not allow the Agency to perform qualitative or quantitative risk assessments concerning occupational exposures. Further, the subpopulations of nonasbestiform ATA which, based on mechanistic and toxicological data, may be associated with a carcinogenic effect, do not appear to present an occupational risk. Their presence in the workplace is not apparent from the record evidence.

1. Human Studies

Summary

The epidemiologic studies submitted to this record consisted of no studies which were not available to OSHA at the time of the proposal. The interpretations submitted in comment and testimony also reiterated positions taken prior to the proposal, although participants expanded on them. Additional analyses concerning reported cases of cancer in the NIOSH study cohort were submitted, both in support of the position that the talc exposure was correlated to cancer, and in support of the opposing view that smoking was a likely cause of any elevated SMR.

A review of the human studies in the record follows: Where no new interpretative comment was offered, only a summary describes it. Where new comment or updated data was submitted, a discussion is presented. The discussion is organized around the categorization of the minerals to which the cohorts were exposed. As discussed at length in the proposal, uncertainty about the content of the mineral exposure at times made definitive interpretation difficult. However, because the substances to which workers are exposed are mixed, OSHA believes that mixtures can be evaluated in their own right. If disease cannot be correlated to exposure to a specific mineral in a mixed mineral product, then prudent health policy allows OSHA to ascribe causation to the mineral mixture, rather than to any component.

a. *Studies of exposures to ATA and asbestos contaminated ores.* As OSHA noted in its proposal, McDonald et al. (Ex. 410–6) reported an excess of respiratory cancer including mesotheliomas, among vermiculite miners in Libby, Montana. Vermiculite, a mica-like mineral ore, was contaminated with four to six percent tremolite-actinolite fibers. Mineralogic analysis of the Libby mine's ore showed the fibers to be mostly an asbestiform type of fiber. However there were also "massive amphibole crystals, which when pulverized produced cleavage fragments resembling fibers" (p. 439). OSHA noted, "[a]lthough the fiber analyses indicate that some of the particles were non-asbestiform in origin, the predominant fiber exposure appears to be from asbestiform tremolite. * * * Standardized Mortality Ratios (SMRs) were computed for the cohort of 406 Men. When compared to death rates of men in the U.S., there was a substantial excess number of deaths from respiratory cancer (SMR = 245). Four of the 43 deaths were from mesothelioma. There was also a substantial excess number of deaths from non-malignant respiratory disease (SMR = 255). There was no excess number of deaths from cancers of non-respiratory sites. When compared to the death rates of Montana men, the cohort's excess mortality was even greater; for example the SMR for respiratory cancer rose from 245 to 303." OSHA stated in the proposal that the result of the Libby, Montana study and other studies of workers exposed to tremolite asbestos contaminated ores "provide additional evidence on the high potency of asbestiform tremolite. Although non-asbestiform tremolite was present it is not possible, from the data presented, to discern what contributing effect the non-asbestiform minerals may have had." (55 FR 4944).

Most comment and testimony during the rulemaking concerning the Libby Montana study reiterated OSHA's earlier analysis. The American Thoracic Society pointed out that the mineralogic characterization of the Libby deposit as containing tremolite asbestos has been challenged, and for that reason and because this is a "non-replicated" study, warned against relying on it. (Ex. 525, p. 5) Dr. Nicholson, in his testimony, pointed out that the presence of nonasbestiform minerals in the deposit, made the study compatible with the risk expected on the basis of measured fiber concentrations (Tr. 5/8, p. 55). NSA noted that "the Libby vermiculite workers were exposed to asbestiform tremolite and asbestiform actinolite and thus this study is not useful in the examination of the nonasbestiform ATA question." (Ex. 524, p. 26.) As stated in the preamble to the proposal, OSHA believes that the results of the Libby, Montana study, and other studies where miners were exposed to both asbestos tremolite and nonasbestiform tremolite (see e.g. Kleinfeld et al., Ex. 84–402 and Brown et al. (Ex. 84–25) provide additional evidence on the high potency of asbestiform tremolite. Although nonasbestiform tremolite was present it is not possible from the data presented, to discern what contributing effect the nonasbestiform minerals may have had to the excess cancer observed in this study.

b. *Studies of exposures to mixtures of other nonasbestiform analogues with nonasbestos minerals.* The Homestake gold mine study (Ex. 84–45, Docket H–033c) was a retrospective cohort mortality study of 3328 gold miners who worked in full-time underground jobs for at least one year between 1940 and 1965. There were 861 observed versus 765 expected deaths overall. The primary exposures were to amphibole minerals in the cummingtonite-grunerite series (the nonasbestiform analogue of amosite) and silica. According to the study's investigators "no association, as measured by length of employment underground, dose (total dust × time), or latency was apparent with lung cancer mortality (43 observed vs. 43 expected). However Dr. Nicholson noted that the conclusion of no excess lung cancer risks associated with exposures at the mine was based on calculations using U.S. mortality rates, rather than South Dakota mortality rates. Had South Dakota mortality rates been used, SMRs would have been raised to 160, rather than the 100 reported by the investigators. (Tr. 5/8, p. 81–2). Dr. Bob Reger who testified for the American Mining Congress (AMC) suggested that such an adjustment is improperly made without adjusting for age (See Tr. 5/8, p. 82). Although OSHA believes that uncertainty in interpretation is introduced by the study's use of U.S. mortality rates, reconstruction of the SMRs applying the South Dakota mortality rate is hindered by the lack of data which would allow an age specific reconstruction. Dr. Nicholson also noted that the Homestake results were not incompatible with an asbestos effect, because in the longer duration category there is a total of only three deaths, an additional uncertainty, and there is a possibility that one has individuals that are survivors and "* * * demonstrate a lower risk by virtue of the fact that they could have had lesser exposure jobs, and, thus, be at lesser risk * * *" (Tr. 5/9, p. 83). OSHA believes Dr. Nicholson's comments correctly state some uncertainties of the study, i.e., small number of deaths, and the possibility that retirees can be a survivor population. These uncertainties do not, by themselves, provide a basis for interpreting the Homestake studies as confirming evidence for the carcinogenic effect of nonasbestiform minerals. The study is not inconsistent with a positive association and does not prove that there is no association. However, it can also not be interpreted as clear evidence of association.

Other studies concerned two groups of iron ore miners and processors, who were exposed to taconite dust which may have contained cleavage fibers of the cummingtonite-grunerite series (Higgins et al., 1983 (Ex. 410–18); Cooper et al., 1988 (Ex. 427)). OSHA agrees with the analysis of all participants who commented on these studies, to the effect that they do not inform as to the carcinogenicity of nonasbestiform ATA, perhaps because of the low exposures in one mine and the lack of latency to observe lung cancer in the other (See

e.g., NSA's post-hearing brief (Ex. 524, p. 27), Dr. Nicholson's testimony (Tr. 5/8, pp. 55–56)).

In its proposal OSHA described at considerable length the studies of the New York State tremolitic talc miners and millers, which had been undertaken by NIOSH. The entire preamble discussion is incorporated here (see 55 FR 4946). One significant interpretive issue concerns the mineral content of the deposit and thus the employees exposures. Vanderbilt testified that "the ore composition is fairly consistent * * * the content of the talc being between 20 to 40 percent, serpentine, 20 to 30 percent; the tremolite 40 to 60 percent, the anthophyllite between zero and five (percent), and * * * quartz * * * in very trace amounts." (Tr. 5/11, p. 103). Testimony in the record supports Vanderbilt's claim that any of the asbestos minerals that falls into the scope of this standard is not a component of the ore. (See Langer et al., and Dunn GeoScience in the prehearing submission of the American Mining Congress and the NSA, Ex. 479–6, 479–23; R.J. Lee in the Vanderbilt Dust Project, Ex. 433). While the reports of these analysts find no evidence of the six asbestos types in the Vanderbilt talc mines, all three noted the presence of asbestiform talc fibers and "transitional particles". These are the same "transitional particles", described earlier in the section on Mineralogic Considerations, which resemble asbestos and talc but are not technically asbestos. NIOSH reiterated its original evaluation that the Vanderbilt deposits contained asbestiform as well as nonasbestiform tremolite and anthophyllite. (See Tr. 5/9, p. 11.) OSHA notes that the debate over the mineralogic content of the Vanderbilt mines remains unresolved. OSHA believes however that the presence of asbestiform talc and the so called "transitional particles" together with the undisputed presence of nonasbestiform tremolite and anthophyllite may have led to the identification of various particles as asbestiform tremolite and/or anthophyllite.

Various industry and government sponsored reviews and updates of NIOSH's study have been conducted. In the NPRM, OSHA concluded that "the NIOSH studies provide evidence to support the possibility that exposure to minerals at the mine is correlated to the excess mortality from lung cancer and nonmalignant respiratory disease and an excess of pleural thickening and lung decrements. However due to uncertainties in the mineral content and mixed mineral contents, the study does not show that it is more likely than not that non-asbestiform fibers are the cause of the disease." (55 FR 4947).

A former NIOSH researcher, Dr. John Gamble, who has criticized basing the regulation of ATA as asbestos on the NIOSH study, submitted additional material to substantiate his contention that attributing excess cancer to nonasbestiform ATA was speculative (Ex. 478–8). Gamble performed an update and re-evaluation of the 1980 NIOSH study in which he added eight more years of follow-up, an exposure latency analysis, and a nested case-control study to control for smoking and other occupational exposures. In his analysis Gamble found a significant increase in mortality for all cause (SMR=128), all respiratory diseases (SMR=251), all malignant neoplasms (SMR=145), and lung cancer (SMR=207). The lung cancer SMRs were elevated in the 20–36 year latency group (SMR=258) and for workers with less than one year tenure at the mine (SMR=357). In the nested case-control study Gamble found no apparent increased risk associated with non-Vanderbilt jobs. However he did find that the odds ratio for cases who smoked was six times that of combined ex-smokers and nonsmokers. Gamble stated in his conclusions that "Although lung cancer SMRs are elevated, we could not find an exposure-response relationship. The lack of an increased risk of lung cancer is consistent with other mining populations exposed to nonasbestiform minerals. The time occurrence of lung cancer is consistent with a smoking etiology." (Ex. 478–8, p. 2)

NIOSH has stated that Dr. Gamble's opinions "are his alone; arise from activities he performed which, in part, created the appearance of a conflict of interest; and represent conclusions, as judged by independent reviewers, which are not supported by data." (Ex. 520, p. 3). NIOSH continues to support the findings of its earlier studies in the New York talc mines, which, they concluded, provide clear evidence of an increase in lung cancer and other asbestos related disease in talc workers. (Ex. 478–15, Tr. May 8, p. 24)

In its post hearing comments NIOSH submitted an update of the Gouverneur Talc study which added eight new lung cancers to the ten identified in the earlier report (Ex. 532). According to NIOSH the SMR for lung cancer was uniform across tenure strata and increased with increasing latency. There was a statistically significant excess in lung cancer in those with 20 years of more latency and with less than one year employment. Those in this latency group with greater than one year duration also exhibited an increased risk but it was not statistically significant. The increased risk of lung cancer among those with short duration also was observed in the 1989 analysis. (Ex. 532 at p .5). NIOSH offered three explanations: cohort members may have been employed in other New York State talc mines and mills where there may have been additional exposures to the same or to similar types of mineral dust and noted that it is known that half of the lung cancer cases worked on other talc mining operations; some of the short duration group may have had very high exposures; and smoking habits among the employees may have been different from the reference population. However, NIOSH performed an exercise to show that differences in smoking could not account for the observed increase in lung cancer. NIOSH calculated SMRs assuming that 100% of the cohort were smokers. NIOSH noted that the SMR for lung cancer would have been only 160, instead of 207. In addition, the updated results show the SMR for non-malignant respiratory disease was significantly elevated among those with more than one year of tenure (SMR=290, CI 144, 518). The types of nonmalignant disease observed in this study is not known to be smoking related.

OSHA notes, however, that virtually no other participant endorses the NIOSH study as a basis for regulation. For example, the ATS report noted that the results of the case-control study and the lack of any dose-response relationship for lung cancer risk in the cohort study do not support a conclusion that the elevated risk in this population was attributable to mine exposures. (Ex. 525, p. 6) Dr. Richard Morgan, testifying for the NSA, stated that "Even if subsequent studies of the Vanderbilt mine permit a conclusion that an occupational exposure at the mine contribute to the risk, there will remain the problem of deciding which exposures (among many) are likely responsible. At this time, however, there is no evidence from these studies that will permit any conclusion concerning nonasbestiform ATA." (Ex. 490C, p. 180).

In summary, OSHA believes that the epidemiological studies, as a whole, provide insufficient evidence to inform as to the carcinogenicity of nonasbestiform ATA. For example, epidemiological studies involving exposures to nonasbestiform amphiboles other than nonasbestiform ATA are hindered by low "fiber" counts and short latency periods. It is likely that even if exposures had been to

"true" asbestos, a positive response would not have been observed under similar low dose, low latency conditions. Epidemiological studies of upstate New York talc miners are hindered by the fact that workers were exposed to a mixture of minerals [the identification of which is still somewhat at debate]. Although plausible arguments have been presented that suggest that the increase in lung cancer is consistent with a smoking etiology, OSHA believes that it is also likely that exposures at the mine are responsible for the observed disease, especially in the case of nonmalignant respiratory disease. Nevertheless, due to the mixed mineral exposures OSHA concludes that it is not possible from the present data, to determine what role the nonasbestiform ATA may have played in the induction of that disease.

2. Lung Burden Studies

In the proposal OSHA discussed the findings of several lung burden studies. One study discussed the case study of a mesothelioma death in which an analysis of the autopsied lungs showed elevated levels of tremolite [Ex. 410-10]. The fibers of tremolite were of low aspect ratio (i.e. 7:1) and OSHA concluded that low aspect ratio tremolite appeared to have contributed to the induction of mesothelioma (55 FR 4944). However, Mr. Kelly Bailey, testifying for the NSA, took issue with OSHA's conclusion noting that this study involved only a single case study of an individual who was also exposed to chrysotile and the authors of the report stated that the possible effects of tremolite are uncertain. Mr. Bailey also noted that the tremolite "present in the lungs of this case had a *mean* aspect ratio of 7:1" and " * * * it is obvious that a *distribution* of asbestos fibers were found, many with aspect ratios greater than 20:1" (Bailey testimony, Ex. 479-23).

In the proposal OSHA also discussed lung burden studies among miners exposed to both chrysotile and tremolite (Rowlands et al., Ex. 84-178; McDonald et al., Ex. 84-175; Glyseth Ex. 312). These studies indicated that despite high exposure levels of chrysotile, analyses of autopsied lungs showed higher lung burdens of tremolite. OSHA concluded however that the fact that there was a mixture of mineral fiber types precluded one from ascribing causation to one particular mineral type.

The American Thoracic Society [ATS] reviewing the same studies concluded that "although the role of chrysotile versus tremolite in producing disease in these patients could not be clearly sorted out, the * * * data appear to indicate that fairly low aspect ratio fibers of tremolite are capable of causing disease, probably in fairly low concentrations in the case of pleural plaques, but certainly only in very high concentrations in regard to mesothelioma and asbestosis" (Ex. 525, p. 10).

In response to the ATS report, Dr. Arthur Langer, a mineralogist, noted that the "fairly low aspect ratio fibers of tremolite" referred to in the ATS report involve fibers measurements made counting all fibers (i.e. not only those greater than 5 micrometers) and using geometric means. Langer states that "geometric means can be very misleading and the raw data are needed. If one only counts the fibers *longer* than the *Sum* geometric mean, the aspect ratio of the tremolite fibers is greater than 20:1." Dr. Langer adds that "the data from Canada are problematic in that there is a mixed population of tremolite (when present) which skews size distribution in lung burden studies towards short wide 'fibers'. The disease (plaques) may have been caused by thin fibers (asbestos) at the pleura. The thick cleavage fragments in the lung parenchyma may have little to do with the disease process at the pleura" (Ex. 528-7, pp. 15-17).

Lung burden analyses were also performed by Dr. Jerrold Abraham, a physician and pathologist at the State University of New York. In his testimony and written comments to the proposal, Dr. Abraham presented his analyses of the lung tissues of deceased talc miners from upstate New York. Dr. Abraham testified that these analyses showed that the lungs of these talc miners included both asbestos and nonasbestiform minerals, despite the fact that the talc miners are claimed by some parties to be exposed to only nonasbestiform tremolite. (Tr. May 10, p. 119).

However several hearing participants objected to Dr. Abraham's analyses (See Morgan and Reger for the American Mining Congress, Ex. 508; Langer et al., Ex. 511; and the R.T. Vanderbilt Co., Ex. 513). In summary, these commentors stated that the review and analyses of the talc miner cases lacked documentation and included neither smoking histories nor prior occupational exposures. They suggested that these cases may have had heavy smoking histories or prior exposure to asbestos which could have induced the observed disease. In particular Dr. Langer, a mineralogist, stated that the "limitations of the report are so great that the data are reduced to anecdotal observations" (Ex. 511).

OSHA acknowledges the limitation of these analyses. However, the finding of a rare disease such as mesothelioma, among a group of miners exposed to mixed mineral environments, raises concern over these type of exposures. Furthermore smoking is not known to induce mesothelioma. However, as was stated in the case of the Canadian chrysotile miners, the mixture of mineral types precludes one from ascribing causation to nonasbestiform minerals. This problem, in addition to the uncertainties involved in Dr. Abraham's analyses, do not provide sufficient information to conclude that nonasbestiform ATA present a risk similar in magnitude or type to asbestos.

In summary, lung burden analyses indicate that nonasbestiform minerals are present in the lungs of cases diagnosed with lung cancer and mesothelioma. Several arguments have been put forth by hearing participants both for and against the implication that nonasbestiform contributed to the observed disease. OSHA believes that it is difficult to discern what contributing effect the nonasbestiform minerals may have had because other asbestiform minerals are also present.

3. Animal Studies

a. *Mechanistic studies.* OSHA noted in the proposal that several studies in the record suggested that fiber dimension is an important factor in asbestos-related disease development. (55 FR at 4944). Dr. Merle Stanton's landmark study (Stanton *et al.* [Ex 84-195, Docket H-033c]) is generally accepted as showing that fiber dimension is an important determinant in mesothelioma production. Dr. William Nicholson, testifying for OSHA described Stanton's study in his testimony. "Seventy-two separate experiments were conducted with different mineral materials, including the commercial asbestos varieties, man-made mineral fibers and minerals containing varying other percentages of fibers. The results of those studies indicated, and his major conclusion was, that the length and diameter of the fibers were the most important factors determining carcinogenicity. Longer fibers were more carcinogenic than shorter ones, and thinner ones more so than thicker ones * * *." (Tr. 5/8, p. 40).

Most comment and testimony acknowledged that Stanton's work demonstrated that fiber dimension is generally related to tumor production. (See e.g. NSA's post-hearing brief at 19, Ex. 524; Dr. Oehlert's testimony Tr. 5/9, p. 88) For example, Dr. Oehlert, a statistician testifying for NSA stated "In

agreement with Stanton, I find that the log number of index particles per microgram in a sample is the best single predictor of tumor probability for that sample. The index particles—I believe the term was coined by Stanton—are those particles longer than 8 micrometers and narrower than .25 micrometers." (Tr. 5/9, p. 88).

However, participants disagreed over more specific interpretations of Stanton's study. For example Dr. Nicholson (Ex. 484, Tr. 5/8), NIOSH (Ex. 478-15, Tr. 5/9), and Dr. Groth (Tr. 5/10) asserted that Stanton's work showed that all fibers with certain dimensions had tumorigenic potential; that the greatest correlation existed between fibers of a diameter less than .25 micrometers and greater than 8 micrometers (the "index particles"), but that even a size dimension of 4 to 8 micrometers in length, with a diameter of .25 to 1.5 micrometers had a correlation coefficient of .45. (See e.g. testimony of Dr. Nicholson, 5/8 at 41).

The NSA, in its cross-examination and post-hearing submissions, challenged the interpretation that Stanton's studies show that fibers with aspect ratios as low as 3:1 or 5:1 increase tumor response stating:

> During the hearing testimony, the fact that all of the studies involved exposures to a population of fibers or particulates was consistently agreed upon. This fact does not allow one to attribute a specific aspect ratio or dimension as the cause of a response in these animal studies * * *. It is important to recognize that the entire particle size profile of the exposure (width, length, and aspect ratio distribution) contributes to the results of any study. When one looks at the particle width, length, and aspect ratio distributions of cleavage fragments and compares these same distributions to those for asbestos, the population characteristics are easily seen to be quite different * * * (NSA, post-hearing brief, Ex. 524 at 16).

Various statistical analyses of Stanton's studies were submitted. The study cited as supporting low aspect ratio toxicity, is Bertrand and Pezerat (Ex. 84-114, Docket H-033c). OSHA described this study in its proposal as finding "a high correlation between aspect ratio and tumor probability for durable minerals. In their analysis tumor probability began to rise at aspect ratios of about 3 to 5". (55 FR at 4944). However, the Bureau of Mines stated in their comments that OSHA did not fully describe Bertrand and Pezerat's findings. They pointed out that "the slope of the curve was extremely small at 3:1 to 5:1 aspect ratios and aspect ratios of 3:1 to 5:1 represent about 5 percent probability (base level in the study)" and "No indication was given as to whether 5 percent is statistically significant to control populations." (Ex. 478-6) Similarly the NSA stated that since Bertrand and Pezerat's "analyses deal with distributions of aspect ratios, it is inappropriate to suggest that an aspect ratio of three or five or any specific value is the reason for the carcinogenic response". (Ex. 524, p. 22).

NSA's witness, Dr. Gary Oehlert presented a statistical reanalysis of Stanton's data. Dr. Oehlert stated that his analysis showed that the log number of index particles was the most significant predictor of tumor probability and once index particles have been accounted for, aspect ratio has no further predictive information to provide. (Tr. 5/9, p. 90). However, it should also be noted that although Dr. Oehlert concluded that the number of index particles is the "best" predictor of tumor probability, his analyses also show that aspect ratio is statistically significantly correlated to tumor probability. Dr. Oehlert suggested that this correlation is likely due to the fact that aspect ratio is related to the number of index particles. Nevertheless he states that nonindex particles may contribute to carcinogenicity, but that the Stanton data are not precise enough to determine their influence. In addition, Dr. Oehlert noted that the mineral type is a significant predictor of tumor probability * * * and should be included when estimating tumor risk. (Tr. 5/9 at 2-87).

Dr. David Groth, a pathologist, testifying on his own, concluded from review of Stanton's work that "the results of these studies (i.e. Stanton's) clearly document the importance of fiber size and the induction of cancer by fibers. They also indicate that the chemistry and crystalline structure of the fibers play either no role or a secondary role in the induction of cancer by fibers." Dr. Groth stated that "the results of these experiments have not been seriously challenged by data derived from other animal experiments, and remain as valid today as they were in 1981" (Tr. 5/10, pp. 30-31).

Other dimensional hypotheses were also submitted to the record. Dr. Morton Lippman's 1988 paper which, after reviewing various human and animal studies, identified dimensional ranges for different health effects, was submitted by NIOSH (Ex. 478-15) and others (NSA, Ex. 479-23; AMC, Ex. 479-6). Based on his review of animal injection studies and human lung analyses, Dr. Lippman concluded that the various hazards associated with asbestos (i.e. asbestosis, mesothelioma and lung cancer), are associated with critical fiber dimensions and these dimensions are different for each disease. For example, Dr. Lippman concluded that asbestosis is most closely associated with the surface area of fibers with lengths greater than 2 micrometers (um) and widths greater than 0.15 um; mesothelioma is most closely associated with the number of fibers with lengths greater than 5 um and widths less than 0.1 um; and lung cancer is most closely associated with the number of fibers with lengths greater than 10 um and widths greater than 0.15 um.

The data in the record support and OSHA concludes that fiber dimension is certainly a significant determinant of biological function. OSHA also concludes that despite the various reanalyses of the Stanton study, the basic premise of this study still holds true, that is, that tumor probability increases with the number of long and thin durable particles. However the data available are not precise enough to determine at what point there is no significant carcinogenic potential.

OSHA further concludes that longer, thinner fibers are likely to be more pathogenic. The evidence shows that dusts containing cleavage fragments, rather than asbestiform material, contain substantially fewer longer thinner particles. Thus, a dimensional theory of pathogenicity does not by itself demonstrate that nonasbestiform ATA has similar health effects to asbestos. Even if dimension were the principal determinant of biologic potential for mineral dusts, the evidence in this record is not sufficient to allow OSHA to draw the line for regulation for nonasbestiform ATA at specific dimensions.

b. *Empirical studies.* OSHA stated in the proposal that the empirical studies in animals are not sufficiently supportive of the mechanistic information to conclude that the risks are similar in magnitude and type for both asbestiform and nonasbestiform minerals. (55 FR at 4946). Although OSHA discussed a preliminary report of early results in its proposal, the one totally new study submitted to the record concerned intraperitoneal injection studies in rats of six samples of tremolite of different morphological types conducted by a Scottish team consisting of John Davis, John Addison and others. Dr. Addison testified at the hearing and submitted both draft and final papers describing the experiment (Ex. 479-22; Tr. 5/11). In this study six different samples of tremolite of different morphological types were prepared as dusts of respirable size and used in intraperitoneal injection studies in rats. Three samples were identified as

being tremolite asbestos (California, Korean and Swansea samples). A fourth sample, called Italian tremolite, was initially identified to be nonasbestiform but was later identified, after the tumors were observed, as a "brittle type of fibrous tremolite". The two remaining samples were identified as nonasbestiform tremolite (Dornie and Shinness samples). The three asbestiform tremolite samples produced mesotheliomas in almost all animals tested (California, 100%; Swansea, 97%; and Korean, 97%). The Italian sample which had "relatively few asbestos fibers" produced mesotheliomas in 67% of the animals tested although at significantly longer induction periods. The two remaining samples produced "relatively few tumors" (Dornie, 12% and Shinness 5%) and were considered, by Dr. Addison to be within the range of background incidence of mesotheliomas observed in historical controls in his lab.

TABLE 1.—SUMMARY OF SURVIVAL DATA AND FIBER NUMBER FOR 10MG DOSE

Sample	#animals	#mesothelomas n(%)	Median survival time (days)	#fibers (10^3)/mg	#fibers (10^3)/mg len. >8um dia. <.25
Calif	36	36 (100)	301	13430	121
Swansea	36	35 (97)	365	2104	8
Korea	33	32 (97)	428	7791	48
Italian	36	24 (67)	755	1293	1
Dornie	33	4 (12)	*	699	0
Shinness	36	2 (5)	*	383	0

*Not calculated; table extracted from Davis et al. (Ex. 479-22).

From these results Dr. Addison concluded that all the samples possessed some potential to produce mesotheliomas. However, he pointed out two apparent anomalies. One, the Swansea sample had fewer fibers than the Korean sample, but both produced a maximum response. Dr. Addison explained that one possible explanation may be that the relationship between fiber number and mesothelioma production is blurred by the overdose situation (i.e. a saturation effect). The second anomaly noted by Addison was the difference in fiber number and mesothelioma production between the Italian and Dornie samples. From Table 1 above, as presented in the Addison study, the Italian sample had 1293×10^3 fibers/mg and the Dornie had 699×10^3 fibers/mg. Dr. Addison notes however that when only those fibers from this group (i.e. fibers with aspect ratios >3:1) which have lengths greater than 8 um are counted, the Italian sample had ½ fewer fibers, but produced a higher percentage of tumors (See for example Tables 2(d) and 2(e), Ex. 470-22). Addison also states that while "it is true that many of the long fibers in the Dornie specimen were greater than 1 μm in diameter * * * if only fibers greater than 8 μm in length and less than 0.5 μm in diameter were considered, the two specimens have approximately equal numbers which still does not conform to their very different carcinogenic potential." (Ex. 479-22, p. 13).

This study was interpreted differently by various participants. The NSA and National Aggregates Association's joint submission found the results of the Davis et al study consistent with its position that "the higher the proportion of tremolite federal fibers (i.e. particles with aspect ratios > 3:1) with widths less than 0.5 μm, the greater the incidence of tumors. Conversely, the higher the proportion of tremolite federal fibers with widths greater than 1 μm, the lower the incidence of tumors." (Ex. 529-6, p. 3). The NSA in its post hearing comments further stated that the Davis et al. data "showed an absence of excess tumors from nonasbestiform ATA, and that the best parameter to explain the formation of tumors was the number of >32:1 aspect ratio Stanton particles, not 3:1 cleavage fragments." (Ex. 524, p. 2)

NIOSH found that the Davis et al. study showed that all forms of tremolite asbestos should be considered carcinogenic, and that it presents no clear evidence indicating that non-asbestiform tremolite is not carcinogenic. However, NIOSH expressed serious concerns about the protocol and presentation of the study as follows: lack of controls or historic incidence data for the strain of rat used; unclear mineralogic classification of various samples, particularly numbers 4, 5 and 6; the small number of fiber and particle counts obtained for each sample may limit the accuracy of the size distributions reported; lack of knowledge concerning the representativeness of the non-asbestiform varieties used, and because of saturation doses causing maximal responses for three samples, dose-response relationships cannot be developed for these samples. NIOSH cautioned that because the study has been neither peer reviewed nor published, lacks controls, and has other defects, it should not be relied upon by OSHA for any significant regulatory decision. (Ex. 532)

Langer et al. took issue with most of the NIOSH criticisms in their post hearing comments (Ex. 550). In particular they state that NIOSH is incorrect in its statement that the mineralogic classification of samples 4, 5 and 6 is unclear. Langer et al. point out that the minerals were characterized by "continuous scanning X-ray diffraction, polarized light microscopy as well as scanning and transmission electron microscopy equipped with an energy dispersive X-ray spectrometer." They also disagree with NIOSH statements that "the small number of fiber and particle counts obtained for each sample may limit the accuracy of the size distribution reported." Langer et al. note that "in each operation 200 fibers of all sizes were counted and measured * * *", and "to improve the statistical quality for long fibers the count was continued only for fibers >5 μm * * * until 100 fibers >5 μm had been counted * * * this was done twice for most of the samples and three for the Ala di Stura (i.e. Italian) and Dornie samples (Ex. 550, p. 7).

Dr. David Groth, a former NIOSH scientist, testifying on his own behalf, disagreed with statements made by Addison that the tumor incidence observed for the Dornie sample (12%) and the Shinness sample (5%) was within the background incidence for historical controls. Dr. Groth contends that this observation is not supported by the data published from Addison's lab. Dr. Groth states that "In two separate publications in 1986 * * * using the same strain of rats (AF/HAN) in full life-span experiments *no* mesotheliomas were observed in 61 control rats in one experiment and 64 control rats in

another experiment." (Ex. 529-1, p. 2) In addition, Dr. Groth cites several other results from Addison's lab which show no background incidence of mesothelioma for this strain of rat. Dr. Groth concludes that "the finding of peritoneal mesotheliomas in 6% of rats injected with the Shinness tremolite sample, is a significant finding and provides further support for Stanton's theory regarding the carcinogenic potential of all fibers, including nonasbestiform fibers." (Ex. 529-2, p. 3).

According to Dr. Addison, a co-author of the study, "the results of the * * * study suggest that a wide ranging group of tremolite samples all possessed some potential to produce mesotheliomas following injection into the rat peritoneal cavity" and "In general carcinogenicity relates to the number of long thin fibers than to any of the other dimensional characteristics of the dusts that were considered but the relationship was by no means exact." (Ex. 479-22, p. 13). Dr. Addison added, however, that "the intraperitoneal injection test is, however, extremely sensitive and it is usually considered that, with a 10 mg dose, any dust which produces tumors in less than 10% of the experimental group is unlikely to show evidence of carcinogenicity following dust administration by the more natural route of inhalation". (Ex. 479-22, p. 14-15). He thus concluded that human exposure to such a material "will certainly produce no hazard."

Based on the record evidence, OSHA believes that the Davis et al study confirms the view that various forms of tremolite have different pathogenic potential. For five of the six samples, constant relationships prevailed between asbestiform fibers and high potency and between nonasbestiform dusts and low potency. Interpreting the Italian sample is more problematic, and only speculative explanations exist for why it is more potent than would have been predicted based on its relatively small number of high aspect ratio fibers.

Other animal studies were the subject of testimony and comment, but the analyses essentially reiterated positions taken by the parties in communications to the Agency prior to the proposal. OSHA described the Smith study in its proposal as follows: "Smith et al injected four different talc samples intrapleurally into hamsters. The samples included fibrous tremolitic talc from New York State, tremolitic talc from the facility studied by NIOSH, tremolitic talc from the Western U.S. and asbestiform tremolite. Only the western talc and the asbestiform tremolite induced tumors in hamsters." (55 FR 4948).

Various mineralogic characterizations of the western talc have been made. Dr. Wylie, in cross-examination, reiterated her earlier characterization of the western talc, as fibrous form of tremolite. Dr. Wylie further explained "it wasn't obviously only a sample of asbestos. I think I referred to it as byssolite." However because evidence of that sample consists of one photograph of that material, Dr. Wylie cautioned against drawing "too many conclusions * * * about that one sample." (Tr. 5/9, p. 235.) OSHA agrees with Dr. Wylie and additionally notes that other deficiencies make the Smith study inconclusive. (See discussion in the preamble to the proposal, where OSHA noted the small number of animals, early death of many animals, lack of systematic characterization of fiber size and aspect ratio; 55 FR 4948).

The few additional animal studies undertaken to examine the toxicity of nonasbestiform ATA, either do not inform or do not show equivalent toxicity of ATA. The 1974 intraperitoneal injection rat study conducted by Pott et al, showed no tumor development for the animals injected with the primarily nonasbestiform actinolite sample (Ex. 479-6). The Cook studies of ferroactinolite fibers, show that the sample which was observed to undergo a higher degree of in vivo longitudinal splitting, resulted in more retained fibers, and in a higher concentration of retained fibers. Dr. Wylie noted that "(t)he durability of amphiboles in vivo is well known and the only way for this sample to break down into fibers of smaller widths is for separation of the fiber bundles to have occurred in vivo. They don't dissolve. Fiber bundles are the hallmark of asbestos and this characteristic is clearly revealed in the behavior of Coffin's ferroactinolite". (Tr. 5/9 at 104). Additional evidence was submitted in support of the view that the ferroactinolite sample was, in significant part, asbestiform. Thus, Dr. Lee concluded, based on his electron microscopic analysis, that as much as 61 percent of the sample may be asbestos with 33 percent existing as bundles (Ex. 490F Attach. A, p.2). OSHA concludes that it is more likely that the ferroactinolite sample that resulted in excess tumors is asbestiform and for that reason, the experimental results are not informative concerning the biological potential of nonasbestiform ATA.

OSHA believes that as a whole the animal experiments conducted confirm that for clearly differentiated dust populations, qualitative differences in carcinogenic potential exist between what is commonly considered "asbestos" and "cleavage fragments". Virtually all participants in this rulemaking agreed with this assessment. Even participants who endorsed regulation of nonasbestiform ATA as asbestos agreed that the longer, thinner fibers were more potent. (See Nicholson at Tr. 5/8, p. 60).

c. *Conclusions.* Based on the rulemaking record before it, OSHA reaffirms its preliminary determination in the proposal that there is insufficient evidence to conclude that nonasbestiform ATA present a health risk similar in kind and magnitude to that of their asbestiform counterparts.

Asbestos is regulated as a carcinogen. Some health effects data relating to nonasbestiform ATA involved exposures to mixed mineral populations or particles which were poorly characterized such that no conclusions could be made regarding the carcinogenicity of nonasbestiform ATA. In other cases there were health effects data in humans, reportedly exposed to nonasbestiform ATA, which did not show excess cancer risks similar to those observed among animals and humans exposed to asbestos. However some of these data suffer from methodological deficiencies (e.g., low fiber exposure, poor animal survival and poor mineralogical characterization). These flaws may limit the studies' ability to detect the carcinogenic potential of nonasbestiform ATA if one is present. However, in many of the studies, asbestiform and nonasbestiform minerals were tested in the same experiment using the same protocol and only the asbestiform minerals induced a positive response. Thus, while the studies' results cannot be used to show that nonasbestiform ATA presents no carcinogenic risk, due to certain methodological flaws, the results from these studies do suggest that if a carcinogenic risk does exist for nonasbestiform ATA, the risk is likely to be substantially less than that of asbestos. Given both the lower potency of any potential carcinogenic risk, and the high degree of uncertainty that would accompany any such estimate, OSHA believes the health effects evidence does not support treating nonasbestiform ATA as presenting a risk equivalent in kind or extent to asbestos.

In addition, OSHA finds that the evidence is insufficient to conclude that exposure to nonasbestiform ATA may result in a significant risk of

nonmalignant respiratory disease (NMRD). Unquestionably, exposure to historic levels of tremolitic talc carried with it a significant risk of NMRD (i.e. pneumoconiosis). For example, studies by NIOSH, of tremolitic talc miners and millers in upstate New York (Ex. 84-181, Docket H-033c) have shown an excess risk for NMRD (SMR = 280), among exposed workers. Similar findings of excess NMRD have also been observed in updated studies of this same group of workers both by NIOSH (SMR = 250) and Gamble et al (SMR = 251) (Exs. 532 and 476-8). Moreover NIOSH concluded in their update, that the observed excess in NMRD is more consistently associated with exposures at the mine. NIOSH's conclusion is based on their observation that a larger excess risk is observed among those employees with greater than one year employment at the mine (SMR = 289) compared to those employees with less than one year employment at the mine (SMR = 194). Even officials at the mine acknowledge the NMRD risk associated with the tremolitic talc. For example, in his testimony at the hearings, John Kelse, an industrial hygienist for the R.T. Vanderbilt Company, stated that "(t)he Company has long believed that excess exposure to our talc—and indeed any talc or mineral dust, can result in pulmonary impairment. We have never claimed otherwise. Non-neoplastic respiratory disease has indeed occurred among our talc miners and to an alarming degree among those exposed prior to the advent of modern dust control systems. * * * We have never denied this pneumoconiosis potential." (Tr. 5/11 at 4-104). Similarly, Dr. Brian Boehlecke, testifying as a medical expert for the R.T. Vanderbilt Company, stated: "So my conclusion is that there is a risk of pneumoconiosis from exposure to the type of talc mined and processed at Gouverneur Talc. I believe this is recognized and acknowledged by the company." (Tr. 5/11 at 4-100).

However although exposures at the mine are attributed to the observed excess in NMRD among exposed workers, the data is insufficient to determine that the nonasbestiform tremolite is the causative agent. The tremolitic talc to which workers are exposed is composed of a variety of different minerals. The nonasbestiform tremolite, although a major constituent, is but one of those minerals. In addition, studies of workers exposed to talcs which do not contain nonasbestiform minerals, have also shown an excess risk of NMRD similar to the excess risk which has been observed among the New York State tremolitic talc workers. (See studies of Vermont Talc workers, Selevan et al; Ex. 479-4 Ex. A). Although the study is too imprecise to conclude that nonasbestiform minerals do not induce pulmonary disease, the study of the Vermont miners does suggest that some agent other than nonasbestiform minerals may be the causative agent in the induction of NMRD. Thus OSHA is unable to conclude that the nonasbestiform content in tremolitic talc is the etiologic agent of NMRD evident at high exposure levels. As a result, OSHA is also unable to conclude that nonasbestiform ATA presents a significant risk of NMRD.

VI. Other Regulatory Issues

a. *Regulatory Options*

In the proposal OSHA discussed a number of regulatory options to the proposed removal of nonasbestiform ATA from the asbestos standards. Because of OSHA conclusions regarding the health effects evidence, certain of these options are not supported by this rulemaking record.

(1) The first option discussed in the proposal is to continue to regulate ATA in the 1986 asbestos standards. The Agency has determined that on this record, there is a lack of substantial evidence to conclude that nonasbestiform ATA presents a risk of asbestos-related disease to exposed workers of similar incidence or magnitude to the risk created by asbestos. Therefore the evidence does not support regulating nonasbestiform ATA exposure in the same manner as asbestos exposure.

The health data are too uncertain to provide a basis for estimating potential risk from nonasbestiform ATA. This evidence is not sufficient to perform a reasonable independent risk assessment for ATA. Therefore, continuing regulation in the same standard, at a different PEL is not a viable option. OSHA concludes that the evidence and analyses available at this time do not show sufficient similarities between nonasbestiform ATA and asbestos to regulate them together.

(2) Another option was to continue to regulate nonasbestiform ATA under the 1972 asbestos standard. However, the conclusion that the record evidence is insufficient to show that nonasbestiform ATA presents a health risk similar in type and magnitude to asbestos and thus should not be regulated under the 1986 asbestos standards, substantially weakens a major rationale for regulating OSHA under the 1972 asbestos standard as well. The 1972 standard was based on the health effects of asbestos and not the nonasbestiform minerals.

Virtually all of the health data submitted and examined in this rulemaking was not available in 1972. Therefore, the determination of health effects for nonasbestiform ATA based on the record of this proceeding is based on more evidence and superior analyses than in any earlier asbestos rulemaking.

Also, OSHA's regulatory decisions are required by law to be based on "the best available evidence". (OSH Act, section 6(b)(5)). Although OSHA is not necessarily required to reopen regulatory determinations when new evidence is presented, once a rulemaking proceeding is held, and new, previously unavailable evidence is submitted to that record on important issues. OSHA may consider the issue in light of such new evidence. The agency notes that it stated its intention to make a new determination on the current record concerning the health effects of nonasbestiform ATA.

In addition, OSHA finds that removing nonasbestiform ATA from the scope of the 1972 asbestos standard will not pose a significant risk to employees exposed to those minerals. OSHA incorporates here, its previous discussion in the health effects section, which sets forth the Agency's view of the evidence relating to the non-malignant disease potential of ATA. The evidence available implicates talc containing ATA as a causative agent of nonmalignant respiratory disease; however, exposure to ATA alone is insufficiently linked to the production of such disease.

As noted above employees exposed to talc containing ATA will be protected under the Air Contaminants Standard (29 CFR 1910.1001). OSHA believes that the application of the talc limit in the Air Contaminants Standard, for that portion of their exposure which is related to talc, or the standard's mixture formula, will protect exposed employees against a significant risk of nonmalignant disease.

Also, removing the protection of the 1972 asbestos standard from workers exposed to nonasbestiform ATA will not leave them with a significant risk of developing malignant disease. OSHA has found that the available evidence is insufficient to conclude that exposure to nonasbestiform ATA is linked to the development of cancer. The suggestion that long thin fibers of nonasbestiform ATA, which exceed the dimensions for counting asbestos fibers, may have carcinogenic potential was not disproven by the evidence in this proceeding, however, neither was it supported by substantial evidence. Also, even if long, thin nonasbestiform ATA

fibers have some carcinogenic potential, the record shows that it is not likely that workers may be exposed to a significant risk from such fibers if the 2 f/cc limit of the 1972 standard is lifted.

First, evidence in the record indicates that, long, thin particles of nonasbestiform ATA occur infrequently. For example, in the industries using tremolitic talc, which are the industries with the highest potential exposure to ATA, there is little evidence that exposures to long, thin particles of nonasbestiform ATA have ever exceeded the 1972 asbestos limit of 2 f/cc. Nor is there evidence that nonasbestiform ATA particles, appearing as a contaminant of any other industrial product (e.g. crushed stone products), attain enhanced dimensions which, if measured, would exceed the 2 f/cc limit of the 1972 standard. Second, there are no dose-response data which can be used to derive a quantitative risk estimate for nonasbestiform ATA as a carcinogen, so OSHA's risk estimate for ATA would be based on qualitative information. The approach formerly considered most promising, basing ATA risk on asbestos risk, has been rejected by the Agency, as explained at length in this document. The Agency believes that no other qualitative approach to assessing nonasbestiform ATA carcinogenic risk is supported by the evidence.

Third, for the industries with the highest potential ATA exposure, which includes those which purchase tremolitic talc as a constituent of products such as ceramic tile and paint, the talc limit, and the mixture formula in the Air Contaminants Standard will apply. OSHA believes that these limits will protect employees against any possible excesses of any malignant disease as well as non-malignant disease.

Therefore, OSHA finds that removing nonasbestiform ATA from the 1972 standard meets the requirements set out by the Supreme Court for agency deregulation in Motor Vehicles Manufacturers Association v. State Farm Mutual Automobile Insurance Co. (State Farm), 463 U.S. 29, 1983, and is consistent with Agency interpretations of that decision.

(3) The third option discussed in the proposal is to exclude nonasbestiform ATA from the scope of the revised asbestos standards and to initiate a separate 6(b) rulemaking for either industrial talc (tremolitic talc) or nonasbestiform ATA minerals which attain certain dimensions, such as a 3:1 aspect ratio and are longer than 5 μm. As stated above, the results of OSHA's examination of the health effects evidence in this proceeding do not provide sufficient data to permit the Agency to estimate the risk, if any, to exposed employees from continued exposure at the 1972 asbestos standard's PEL of 2 f/cc, or at current exposure levels in covered places of employment. There was agreement among participants who addressed the issue that exposure to tremolitic talc at historic levels is associated with excess nonmalignant respiratory disease (see e.g., Dr. Boehlecke, testifying for R.T. Vanderbilt, at Tr. 5/10, pp. 100–101). OSHA's contractor estimated current exposure levels in industries using such talc containing products, even without local exhaust ventilation, as far less than such historic levels. (See CONSAD report, Ex. 465). No additional data concerning exposure levels of such workers was submitted to the rulemaking record. With no basis to estimate risk to exposed employees from talc containing nonasbestiform ATA, OSHA is unable to formulate a proposed standard to protect such workers at this time. As stated above, OSHA believes that the application of the appropriate exposure limits in the Air Contaminants Standard to exposures to constituents of tremolitic talc, and to ATA, will protect employees against significant risks of disease.

If further information is submitted to OSHA in the future, which shows that workers in industries using talc containing nonasbestiform ATA, or other nonasbestiform ATA using industries, are at present risk of developing exposure related disease, OSHA may reconsider this regulatory decision.

(4) The fourth option is to regulate nonasbestiform ATA under a specific listing in the air contaminants standard, including consideration of a listing for nonasbestiform ATA. OSHA has chosen this approach but nonasbestiform ATA will be covered by listing for particulates not otherwise regulated (PNOR) in Table Z–1–A of 1910.1000 (15 mg/m (total dust); 5 mg/m (respirable dust)), which is designed to protect against the significant risk of respiratory effects which all particulates create at higher levels of exposure.

OSHA is not regulating ATA under the listing for talc. OSHA notes that the health evidence concerning the nonmalignant disease potential of talc containing tremolite is not specific to any one component of the product, and there is evidence suggesting that talc, not containing nonasbestiform ATA, also may cause respiratory disease (See for example the preamble to the Air Contaminants Standard, 54 FR at 2526). Accordingly, OSHA revised the PEL for talc to 2 mg/m^3 on January 19, 1989 (54 FR 2332 to 2983, 29 CFR 1910.1000). As talc causes respiratory disease and nonasbestiform ATA as a particulate causes respiratory effects, OSHA concludes that when workers are exposed to mixtures of such dusts with different PELs, the mixture formula applies. Where exposure is to talc containing nonasbestiform ATA, if the employer wishes to avoid separately identifying each component to apply the mixture formula, the entire product may be considered as the substance with the lower PEL.

b. *Fiber Definition Issues*

During this rulemaking the NSA and other participants requested that OSHA validate for industry a feasible method of distinguishing asbestos fibers from nonasbestiform particles or other mineral particles which meet the dimensional cutoffs in the asbestos standards. Further, OSHA is asked to define "asbestos" in terms of such differential counting strategy. NSA agrees with the Agency that when the environment is one in which "known asbestos is likely to be the only airborne particle of regulatory concern, it (3:1 aspect ratio criterion) can be an acceptable and economical basis for monitoring worker exposure to substances that pose health risks." (479–1G, p. 22). However, in the crushed stone industry, other particles, NSA insists, will be counted even though they are not asbestos, or even nonasbestiform minerals simply because they have attained aspect ratios of 3:1. OSHA does not believe these scenarios are realistic. The asbestos standards have been in effect since 1972; yet industry presented no data, evidence or testimony that showed the impact of the 3:1 aspect ratio on the crushed stone industry. Producers should know if their products contain asbestos fibers, by surveying deposits, examining hand samples, and doing bulk sampling.

The issue of whether individual fibers of ATA can be identified as to mineral type was further addressed by other witnesses. Dr. Arthur Langer, testifying on his own behalf, noted that "* * * in some instances single, isolated particles may be impossible to distinguish, i.e., acicular cleavage fragment from asbestiform fibril". (Ex. 517, Tab 5). Dr. Spooner pointed out that identification of an airborne fiber is hindered, when as happens in an industrial hygiene setting "we don't have the opportunity to know where the material is coming from, nor do we have the opportunity to look at a very large population of fibers * * *". (Tr. 5/8, p. 117–118). NIOSH testified

that it was "unaware of any routine analytical methods that can be used to differentiate between airborne exposures to asbestos fibers and nonasbestiform cleavage fragments that meet the microscopic definition of a fiber." (Tr. 5/9, p. 13).

The OSHA reference method may be insufficient in mixed fiber environments to distinguish asbestos from other particles in all cases. However, OSHA believes that currently, producers and users of mineral products feasibly identify asbestos and distinguish it from other mineral fibers or particles. Dr. Langer noted "I would use polarized light microscopy to characterize materials used in the work place or characterize mine environments. Someone has to go to some mine or quarry or operation or plant or factory to see whether or not asbestos materials are present, and there are standard techniques to analyze materials and find out whether or not asbestos is present. You could use phase contrast microscopy once you establish what you're dealing with." (Tr. 5/11 at 226). Dr. Langer recommended that OSHA define "asbestos" as certain minerals which display certain properties, which apply to "large aggregates". Such properties are for example, polyfilamentous bundles, made up of unit fibrils, displaying anomalous optical properties, etc. (Id at 227). Dr. Addison commented that for "at the last eight years we've been training a regular number of people in polarized light microscope techniques, * * * to recognize the characteristic properties on the macroscopic scale and on the microscopic scale, to come up with what we consider to be a fully authoritative identification of the material as asbestos. It's really not a difficult task." (Ibid).

Dr. Langer also noted that in his knowledge the former Manville Corporation routinely used polarized light microscopy in many of their plants to analyze air samples, where manmade vitreous fiber was mixed with asbestos fiber" (Tr. 5/11, p. 225).

OSHA also notes that differential counting of fibers has been performed by its laboratory and other laboratories in the past. According to the Agency's chief microscopist, identification of individual fibers is assisted by knowledge of the source of the contaminant, the industrial context, and the skill of the microscopist. (Ex. 410-23).

However, Dr. R.J. Lee, testifying on behalf of the NSA, presented a new analytical method for use in mixed mineral environments. (Ex. 490F) This method was presented as a differential counting procedure for assessing the asbestiform particle population in dusts that include both asbestiform and nonasbestiform particles. Dr. Lee's proposed method uses the current NIOSH 7400 PCM method but in addition incorporates steps to account for particles with widths less than 1 micrometer and particles which are bundles in order to differentiate between those particles which are fibers and those particles which are cleavage fragments.

During the hearing Dr. Lee was questioned as to the validity of this method and whether or not it would alter asbestos counts. In response to this questioning Dr. Lee conducted and submitted the results of a round robin analysis of his proposed method (Ex. 534). In the round robin analysis 6 different labs performed comparisons of particle counts on a variety of different dust samples using the current NIOSH 7400 PCM method and Dr. Lee's proposed method. Although somewhat limited, the results of the round robin analysis indicate that there is little variability between the asbestos fiber counts using the NIOSH method and the asbestos fiber counts using Lee's proposed method. However, according to Dr. Lee, the proposed method allows one to differentiate between asbestos fibers and nonasbestiform cleavage fragments more readily than current differential counting procedures.

Despite the fact that the proposed method appears to provide a feasible means of discriminating between asbestiform fibers and nonasbestiform cleavage fragments, OSHA is reluctant to change its current approved methodology based on such limited data (i.e. one round robin analysis), especially since the Agency notes that changes to the asbestos standards affect a much wider regulated community than participants in this rulemaking. OSHA believes that the adoption of any method would require more extensive testing using a broader range of samples more closely associated with the typical types of occupational exposures covered by the OSHA standards. In addition, considerable expenditures of time and money could be required to insure that labs are adequately training technicians and proficiently using the new method. Before such costs are imposed OSHA believes it would be prudent to better examine the validity of a new method. The Agency notes that the high hazard presented by asbestos exposure requires that any regulatory change affecting counting asbestos fibers err on the side of worker protection. OSHA believes that the burden on employers in affected industries to show that particles are not asbestos is not unreasonable, given the risk presented by undercounting of asbestos, and the claims that asbestos contamination of nonasbestiform products is not common. For these reasons, as well as the fact that OSHA has acknowledged and allowed the use of differential counting with the current method, the Agency does not believe it is either appropriate or necessary at this time to change its current analytical method. The Agency intends to include in its compliance policy governing mixed fiber settings, provision for the introduction of appropriate evidence concerning fiber width, and other relevant evidence to show that particles counted by PCM are not asbestos fibers.

As discussed in the NPRM, rather than change the analytical procedure, Dr. Ann Wylie proposed changing the aspect ratio from 3:1 to 10:1 as a means of discriminating between asbestos fibers and nonasbestiform cleavage fragments (See 55 FR 4951-52). Dr. Wylie reiterated her proposal in the hearings and presented evidence to show that when populations of particles are viewed with respect to the distribution of their aspect ratios, one can easily distinguish between populations of asbestos fibers and populations of cleavage fragments (Tr. 5/9, pp. 102-107). Dr. Wylie stated that for particles which are greater than 5 μm in length, the majority of nonasbestiform particles have aspect ratios less than 10:1 and the majority of asbestos particles (i.e. fibers) have aspect ratios greater than 10:1. Thus she concluded that changing the aspect ratio from 3:1 to 10:1 provides a means of excluding nonasbestiform particles from particles counts while maintaining the same asbestos particle counts one would have obtained using a 3:1 aspect ratio. However as noted above in this discussion, Dr. Spooner points out that Dr. Wylie's observations, as do her definitions of asbestos, apply to populations of particles and the analyst is often not looking at a population of particles when viewing air exposure monitoring samples (Tr. 5/8, pp. 117-118). Moreover as was noted in the proposal, OSHA is reluctant to change its current method based on the findings of one report. OSHA reaffirms its earlier finding and is not, in this rule, changing its dimensional criteria for aspect ratio in its definition of asbestos.

VII. Summary and Explanation of the Amendments

1. Definitions

Asbestos

In the 1986 revised asbestos standards (29 CFR 1910.1001 and 1926.58) OSHA

amended its definition of asbestos in recognition of the fact that different mineral forms exist. "Asbestos was defined to include only the six asbestiform minerals chrysotile, crocidolite, amosite, tremolite asbestos, anthophyllite asbestos, and actinolite asbestos. However in these 1986 revised standards OSHA also added a definition for tremolite, anthophyllite and actinolite. Tremolite, anthophyllite or actinolite without a modifying term such as asbestos or asbestiform referred to only the nonasbestiform forms of these minerals. This definition was added to make clear that all mineral forms would continue to come under the scope of the revised standards.

In this final rule OSHA retains its definition of asbestos as stated in the 1986 revised standards. However the Agency is removing the nonasbestiform minerals from the scope of the revised standards for asbestos and from all paragraphs, and appendices which reference "nonasbestiform tremolite, anthophyllite and actinolite". This removal is based on the determination, made by the Agency, that the health effects data is insufficient to conclude that the nonasbestiform forms of tremolite, anthophyllite and actinolite present the same magnitude or type of effect as their asbestiform analogues.

VIII. Authority

This document was prepared under the direction of Dorothy L. Strunk, Acting Assistant Secretary of Labor for Occupational Safety and Health, U.S. Department of Labor, 200 Constitution Ave. NW., Washington, DC 20210.

Accordingly, pursuant to sections 4(b), 6(b), 8(c), and 8(g) of the Occupational and Safety and Health Act of 1970 (U.S.C. 655, 657), 29 CFR part 1911 and Secretary of Labor's Order No. 9–83 (48 FR 35736), Construction Work Hours and Safety Standard Act (Construction Safety Act), 40 U.S.C. 333, 29 CFR parts 1910 and 1926 are amended as set forth below.

List of Subjects

29 CFR Part 1910

Asbestos, Hazardous substances, Occupational safety and health.

29 CFR Part 1926

Asbestos, Construction industry, Hazardous substances, Occupational safety and health.

Signed at Washington, DC on this 29th day of May, 1992.

Dorothy L. Strunk,

Acting Assistant Secretary.

Part 1910 of title 29 of the Code of Federal Regulations is hereby amended as follows:

PART 1910—[AMENDED]

Subpart Z—[Amended]

1. The authority citation for subpart Z of part 1910 continues to read as follows:

Authority: Secs. 6 and 8, Occupational Safety and Health Act, 29 U.S.C. 655, 657; Secretary of Labor's Orders 12–71 [36 FR 8754], 8–76 [41 FR 25059], 9–83 [48 FR 35736], or 1–90 [55 FR 9033] as applicable; and 29 CFR part 1911.

All of subpart Z issued under section 6(b) of the Occupational Safety and Health Act, 29 U.S.C. 655(b) except those substances listed in the Final Rule Limits columns of Table A–1–A, which have identical limits listed in the Transitional Limits columns of Table A–1–A, Table A–2 or Table A–3. The latter were issued under Section 6(a) [2a U.S.C. 655(a)].

Section 1910.1000, the Transitional Limits columns for Table Z–1–A, Table Z–2 and Table Z–3 also issued under 5 U.S.C. 553. Section 1910.1000 the Transitional Limits Column of Table Z–1–A, Table Z–2 and Table Z–3 not issued under 29 CFR part 1911 except for the arsenic, benzene, cotton dust, and formaldehyde listings.

Section 1910.1001 also issued under section 107 of Contract Work Hours and Safety Standards Act, 40 U.S.C. 333.

Section 1910.1002 not issued under 29 U.S.C. 655 or 29 CFR part 1911; also issued under 5 U.S.C. 553.

Section 1910.1003 through 1910.1018 also issued under 29 CFR part 653.

Section 1910.1025 also issued under 29 U.S.C. 653 and 5 U.S.C. 553.

Section 1910.1028 also issued under 29 U.S.C. 653.

Section 1910.1030 also issued under 20 U.S.C. 653.

Section 1910.1043 also issued under 5 U.S.C. 551 *et seq.*

Sections 1910.1045 and 1910.1047 also issued under 29 U.S.C. 653.

Section 1910.1048 also issued under 29 U.S.C. 653.

Sections 1910.1200, 1910.1499, and 1910.1500 also issued under 5 U.S.C. 553.

Section 1910.1450 is also issued under sec. 6(b), 8(c) and 8(g)(2), Pub. L. 91–596, 84 Stat. 1593, 1599, 1600; 29 U.S.C. 655, 657.

§1910.1001 [Amended]

2. Section 1910.1001 (including the appendices to the section) is amended as follows:

a. By revising the term "Asbestos, tremolite, anthophyllite, and actinolite" to read "Asbestos" in the section heading, paragraph (j)(4)(i), and appendices B and G.

b. By revising the term "asbestos, tremolite, anthophyllite, and actinolite" to read "asbestos" in the following places: Paragraphs (a)(1), (a)(2), (h)(2)(iii), (h)(3)(ii), (i)(3)(iv), and (j)(5)(iii)(B) and Appendices A, B, G, and H.

c. By revising the term "Asbestos, Tremolite, Anthophyllite, and Actinolite" to read "Asbestos" in paragraph (g)(2) Table 1 heading and Appendices B, H, and I.

d. By revising the term "asbestos, tremolite, anthophyllite or actinolite" to read "asbestos" in the following places: Paragraphs (b) (in the definition for "fiber"), (e)(2), (f)(1)(vi), (f)(1)(viii), (f)(1)(ix), (h)(2)(i), (h)(3)(v), (j)(2)(i), (j)(3), j(5)(iii)(A), (j)(5)(iii)(C), (j)(5)(iii)(E), (k)(1), (k)(2), (k)(3), (k)(4), (k)(5), (k)(6), (l)(2)(i), (l)(7)(i)(A), (l)(7)(i)(C), (l)(7)(ii), (m)(1)(i), (m)(1)(ii)(B), (m)(2)(i), (m)(2)(ii)(C), (m)(3)(ii)(C), (n)(1) and (n)(2).

e. By revising the term "asbestos, tremolite, anthophyllite, and actinolite, or a combination of these minerals" to read "asbestos" in paragraph (h)(3)(iii).

f. By revising the term "asbestos, tremolite, anthophyllite, actinolite, or a combination of these minerals" to read "asbestos" in the following places: Paragraphs (b) (in the definitions for "action level", "employee exposure", and "regulated area"), (c)(1), (c)(2), (d)(2)(iii), (e)(1), (f)(1)(v), (f)(1)(viii), (g)(2) Table 1, (h)(1), (h)(3)(iv), (i)(1)(i), (j)(4)(i), (j)(5)(i), (l)(1)(i) and (l)(4)(i) and Appendices D and H.

g. By revising the term "Asbestos, tremolite, anthophyllite, actinolite, or a combination of these minerals" to read "Asbestos" in paragraph (j)(4)(ii).

h. By removing in paragraph (b) Definitions, the definition "Tremolite, anthophyllite, or actinolite".

i. By removing and reserving paragraph (j)(1)(iii) and by removing paragraph (j)(2)(iii).

j. By removing the Note on the administrative stay at the end of the section.

§ 1910.1101 [Removed]

3. Section 1910.1101 is removed.

Part 1926 of title 29 of the Code of Federal Regulations is hereby amended as follows:

PART 1926—[AMENDED]

Subpart D—[Amended]

4. The authority citation for subpart D of part 1926 continues to read as follows:

Authority: Sec. 107, Contract Work Hours and Safety Standards Act (Construction

Safety Act) (40 U.S.C. 333); sections 4, 6, 8, Occupational Safety and Health Act of 1970 (29 U.S.C. 653, 655, 657); Secretary of Labor's Order No. 12-71 (36 FR 8754), 8-76 (41 FR 25059), 9-83 (48 FR 35736), as applicable.

Section 1926.59 also issued under 5 U.S.C. 553 and 29 CFR part 1911.

§ 1926.58 [Amended]

5. Section 1926.58 (including the appendices to the section) is amended as follows:

a. By revising the term "Asbestos, tremolite, anthophyllite, and actinolite" to read "Asbestos" in the section heading, paragraph (a)(5), and appendix H.

b. By revising the term "Asbestos, Tremolite, Anthophyllite, and Actinolite" to read "Asbestos" in paragraph (h)(2) Table D–4 heading and in appendices B, I, and J.

c. By revising the term "asbestos, tremolite, anthophyllite, and actinolite" to reads "asbestos" in the following places: Paragraphs (k)(3)(iii)(A), (k)(3)(iii)(C), and (k)(3)(iii)(D), and appendices A, B, H, and I.

d. By revising the term "Asbestos, tremolite, anthophyllite, or actinolite" to read "Asbestos" in paragraph (k)(2)(vi)(A).

e. By revising the term "asbestos, tremolite, anthophyllite, or actinolite" to read "asbestos" in the following places: Paragraphs (a)(1), (a)(2), (a)(3), (a)(4), (a)(6), (b) (in the definitions for "competent person", "decontamination area", "demolition", "fiber", "regulated area", "renovation", and "repair"), (d), (e)(6)(iii), (f)(2)(i), (f)(2)(ii), (f)(2)(iii), (f)(7)(i), (f)(7)(ii), (g)(1)(i)(D), (g)(2)(i), (j)(2)(i), (j)(2)(iii)(A), (k)(2)(i), (k)(2)(v), (k)(3)(iii)(B), (l)(1), (m)(4)(i)(A), (m)(4)(i)(C), (m)(4)(ii), (n)(1)(i), (n)(1)(ii)(C), (n)(2)(i), (m)(2)(ii)(B) and (n)(3)(ii)(D).

f. By revising the term "asbestos, tremolite, anthophyllite, actinolite, or a combination of these minerals" to read "asbestos" in the following places: Paragraphs (b) (in the definitions for "action level", "employee exposure", and "regulated area"), (c)(1), (e)(1), (e)(2), (f)(1)(i), (f)(2)(ii), (h)(2) Table D–4, (i)(1), (i)(2)(i), (i)(2)(ii), (j)(1)(iii), (k)(1)(i), (k)(2)(vi)(A), (k)(2)(vi)(B), (k)(3)(i), (m)(1)(i), and (m)(2)(i)(B) and appendix D.

g. By revising the term "asbestos, tremolite, anthophyllite, or actinolite or a combination of these minerals" to read "asbestos" in paragraph (n)(1)(i).

h. By revising the term "asbestos, tremolite, anthophyllite, actinolite" to read "asbestos" in the following places: Paragraph (e)(6)(iii).

i. By revising the term "asbestos, tremolite, anthophyllite, or actinolite or materials containing asbestos, tremolite, anthophyllite, or actinolite" to read "asbestos" in the following places: Paragraphs (b) (in the definition for "removal") and (g)(2)(ii).

j. By removing in paragraph (b) Definitions, the definition "Tremolite, anthophyllite and actinolite".

k. By removing and reserving paragraphs (k)(1)(iii) and (K)(2)(iv).

l. By removing the Note on the administrative stay at the end of the section.

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ATTACHMENT 2

ANALYSIS OF THE COST EFFECTIVENESS OF THE OSHA REGULATION OF NONASBESTIFORM AMPHIBOLES WITH RESPECT TO SELECTED SECTORS OF THE DOMESTIC MINERALS INDUSTRY

by

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EXECUTIVE SUMMARY

On June 20, 1986, the Occupational Safety and Health Administration (OSHA) published a final rule titled "Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite; Final Rules." The regulation, which was amended in September 1988, established exposure limits for asbestos and the nonasbestiform varieties of the amphibole minerals actinolite, tremolite, and anthophyllite (AT&A). In addition, under the OSHA regulation, all products containing a specified concentration of these minerals must be labelled as having a constituent that is a carcinogen. A fourth administrative stay granted by OSHA in the application of the regulation to AT&A is due to expire on November 30, 1990.

A study was undertaken by the Bureau of Mines in April 1989 in an effort to contribute to OSHA's final asbestos standard. The Bureau analysis questions whether OSHA has conclusively demonstrated a health risk associated with AT&A and, consequently, that these minerals should be regulated at all given that no discernible net benefits will result. The Bureau study has also identified a basic inconsistency between OSHA's definition of asbestos and its asbestos standard. The regulation will result in economic impacts on several minerals industry sectors and major technical and legal uncertainties which will affect the economic performance of the domestic minerals industry.

With few exceptions, the OSHA asbestos regulation does not apply to the mining industry because mining and milling operations are regulated by the Mine Safety and Health Administration (MSHA). Given OSHA's present regulation, however, mineral producers must inform their customers of the AT&A content of their products. Because nonasbestiform amphiboles are very common in nature and occur in a variety of geologic environments, a large number of U.S. mineral producers will have to sample and test their products. On this score, confusion and uncertainties in the minerals industry have resulted because of OSHA's lack of guidance on an acceptable bulk sampling procedure.

Businesses that use mine and mill products in their production processes must adhere to provisions of the OSHA regulation. Included are major segments of the minerals industry, such as smelters, as well as other consumers of mineral products such as ready-mix concrete plants, and bulk commodity transfer facilities.

The economic impact of the OSHA regulation is expected to be greatest on the aggregates industry. Due to product liability considerations, it is expected that preliminary deposit evaluation and deposit sampling of some kind would have to be done at about 1,325 quarries, or one fourth of the crushed stone quarries in the

United States. It is estimated that about 780 quarries, or 15 percent of U.S. quarries, would need to conduct detailed testing. The annualized cost of preliminary deposit evaluation and deposit sampling of the 1,325 quarries is estimated at $22 million. The detailed testing component of this cost estimate pertains to only 435 of the 1,325 quarries, or nine percent of U.S. quarries. Significantly, the Bureau analysis concludes that the remaining 345 of the 780 quarries subject to detailed testing, or seven percent of all U.S. quarries, would be financially unable to afford the cost of the required detailed testing because of their small size. These quarries, which produced an estimated 16.6 million tons in 1987 valued at $72.5 million, f.o.b. plant, could be forced to close. Sales losses in the aggregates industry are possible and would be contingent on the availability and cost of material that is essentially free of AT&A and the liability concerns associated with using products containing AT&A.

It is estimated that the domestic talc industry could lose up to $12 million in sales over a period of several years because of substitution arising from product liability concerns of consumers. The iron ore industry could lose sales of minor amounts of ore, in the form of direct shipping ore and concentrates, and the steel industry would have to monitor exposed employees at sinter plants and at some blast furnaces.

The OSHA regulation sets a precedent in the regulation of asbestos. If MSHA, which does not currently regulate AT&A as asbestos, follows OSHA in the upcoming revision of its air quality regulations for mines, the overall impact on the mining industry would be far more significant. For example, 31 percent of 1987 U.S. copper mining capacity could be affected given the geology of these deposits.

The OSHA asbestos regulation, which may be unnecessary given no conclusive evidence of any resultant health benefits and which contains mineralogical errors in its definitions, will result in considerable costs to the domestic minerals industry in ways that the agency did not consider in its formulation. In the concluding section, recommendations are offered to OSHA in an effort to contribute to a regulation, if one is needed, that can be more appropriately applied to the minerals industry.

INTRODUCTION

On June 20, 1986, the Occupational Safety and Health Administration (OSHA) published a final rule titled "Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite; Final Rules" (51 Fed. Reg. 22612). The regulation, which was amended in September 1988 (53 Fed. Reg. 35610), established exposure limits for asbestos and the nonasbestiform varieties of the amphibole minerals actinolite, tremolite, and anthophyllite (AT&A).[1] In addition, under the regulation, all products containing a specified concentration of these minerals must be labelled as having a constituent that is a "cancer and lung disease hazard" (51 Fed. Reg. 22699, 22736).[2]

In response to the regulation, a domestic talc producer filed a petition in the U.S. Court of Appeals for the Second Circuit challenging the portion of the regulation pertaining to AT&A. The case was transferred to the U.S. Court of Appeals for the District of Columbia Circuit.

On July 18, 1986, in response to submissions from the talc company, trade associations, and the National Institute for

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[1]The nonasbestiform varieties of the amphibole minerals actinolite, tremolite, and anthophyllite will be referred to as "AT&A" in this report.

[2]See Appendix A for a more detailed description of the provisions of the regulation.

Occupational Safety and Health (NIOSH), OSHA granted a temporary stay of nine months in the application of the regulation to AT&A. This administrative stay was subsequently extended three times and is due to expire on November 30, 1990 (54 Fed. Reg. 30704).

During the stay, OSHA is enforcing its 1972 asbestos rule, which is less stringent than the 1986 regulation. The 1972 regulation, however, specifically defined AT&A as asbestos. Since OSHA admitted in a 1984 proposed rule that its 1972 asbestos definition was mineralogically incorrect, and that it was the only governmental agency to regulate AT&A as asbestos (49 Fed. Reg. 14122), the agency is paradoxically perpetuating an error that it previously acknowledged.

Due to the presence of AT&A in many ore types, the domestic minerals industry could be adversely impacted by the June 20, 1986 OSHA asbestos regulation. In an effort to contribute to any OSHA decision on AT&A, this study, undertaken in April 1989, evaluates OSHA's asbestos regulation in light of the agency's regulatory mandate, reviews evidence as to whether health benefits would result from the regulation, identifies and examines the inconsistency between OSHA's definition of asbestos and its asbestos standard, the technical and legal uncertainties this has imposed on the domestic minerals industry, and the economic impact on several sectors of the industry. The cost and market impact estimates were developed by Bureau analysts based on data obtained

from the literature and conversations with experts in government, trade groups and unions, consultants and academe, and industry. Implications to the domestic minerals industry of the possible adoption of the regulation by the Mine Safety and Health Administration (MSHA), OSHA's sister agency in the Department of Labor, are also analyzed. In the concluding section, recommendations are offered to OSHA in order to contribute to a regulation, if one is actually needed, that can be more appropriately applied to the minerals industry.

ANALYSIS OF BENEFITS FROM THE OSHA REGULATION OF AT&A

OSHA's Regulatory Mandate

The Occupational Safety and Health Act of 1970 (P.L. 91-596) was passed to assure safe and healthful working conditions in the United States, as far as possible. The Act charges the Secretary of Labor with promulgating safety and health standards to meet this objective. In a 1980 Supreme Court ruling (Industrial Union Department, AFL-CIO v. American Petroleum Institute, 448 U.S. 601, 65 L. Ed. 2d 1010, 100 S. Ct. 2844), however, OSHA was required to find the existence of a significant safety or health risk under a current standard before issuing a new regulation and to demonstrate that a new standard would reduce or eliminate the risk. Specifically, the Court stated that ". . . Before he can promulgate any permanent health or safety standard, the Secretary [of Labor] is required to make a threshold finding that a place of employment

Summary of the Medical Literature on Exposure Risks

Unlike asbestos, AT&A rarely occurs in sufficient quantities in deposits to be economically valuable by themselves. Miners are exposed to AT&A only when a deposit is mined for the recovery of other minerals. In most of the epidemiological studies, the authors noted that exposure to other minerals such as quartz also occurs frequently and that smoking and previous work experience are other critical factors in the interpretation of the health studies.

In Minnesota, iron ore miners are exposed to the amphibole minerals cummingtonite-grunerite, actinolite, riebeckite, and hornblende. Generally, the cummingtonite-grunerite and actinolite are elongate but not asbestiform, and riebeckite is nonasbestiform. Two reports suggest that asbestiform riebeckite (crocidolite) and ferroactinolite are present in small amounts in parts of the deposit.

Clark et al. (1980) studied 249 workers who were exposed to taconite dust for over 20 years at the Reserve Mine operation. No symptoms characteristic of asbestos were reported. Lung disease was attributed to cigarette smoking and silicosis. Higgins et al. (1983) studied over 5,751 workers at the Reserve Mine operation and found no association between mortality and exposure to dust. Although the number of deaths from lung cancer was lower than the control population and no mesothelioma cases were observed, they cautioned that exposures to total dust, silica dust, and fibers were low and the average time since initial exposure was relatively short. Cooper et al. (1986) studied 3,444 workers and found that the death rates were lower than the control populations for lung cancer and respiratory tract cancer. Clark noted that exposures to amphiboles were unknown.

South Dakota miners at the Homestake gold mine are exposed to cummingtonite-grunerite, actinolite, and hornblende. These amphiboles are elongate but not asbestiform. Gillam (1976) reported excess deaths and respiratory malignancies among a study group of 439 workers. He attributed the malignant disease to these amphiboles, with cigarette smoking as a possible cofactor and the nonmalignant disease to amphiboles and possibly free-silica dust. Swent et al. (1976) refuted the study, indicating that NIOSH had underestimated the amount of smoking, that most of the nonmalignant disease reported as asbestosis by NIOSH was classified as silicosis on death certificates, and that exposures to silica were above standards in the past. McDonald et al. (1978) studied 1,321 employees with over 21 years of service with Homestake. Although there was an elevated death rate for respiratory cancers and pneumoconiosis, exposure to silica rather than asbestos was suggested as the cause. Brown et al. (1985a, 1985b) studied 3,328 miners at Homestake. Lung cancer deaths were similar to those of the control population. Respiratory diseases were attributed to exposure to free silica. The Brown report was contested by one coauthor because of the control group used, difficulty in diagnosing the diseases, and ignoring the latency period of asbestos-related diseases.

In New York, talc miners are exposed to anthophyllite and tremolite. These minerals are elongate but not asbestiform. Brown and Wagoner (1980) examined 398 workers who had worked for Gouverneur Talc Co. between 1947 and 1959. They found excess deaths from lung cancer and nonmalignant disease. Several of the workers who died of lung cancer, however, had worked at Gouverneur Talc for less than one year. It was later shown that the number of workers who smoked was greater than expected for a

blue-collar work force (Gamble et al., 1979). Stille and Tabershaw (1982) examined records on 655 workers and concluded that the number of overall deaths and deaths attributed to lung cancer were not significantly greater than the control group.

In Labrador, iron ore miners are exposed to cummingtonite-grunerite and anthophyllite, which are nonasbestiform although some elongated particles are present. Edstrom and Rice (1982) examined radiographs for 2,455 workers with three or more months of employment. They found patterns consistent with pneumoconiosis in 46 of the workers. They also indicated that some workers showed asbestotic symptoms although it was not mentioned in a later report summarizing the findings (Chittai et al., 1983). A later review of 61 of the radiographs indicated that symptoms were consistent with silicosis, siderosis, or a mixed-dust pneumoconiosis and not suggestive of asbestosis.

Relatively few animal studies of the nonasbestiform amphiboles have been conducted. Pott (1974) injected a primarily nonasbestiform actinolite intraperitoneally into laboratory rats and observed no tumors. Smith (1979) implanted both asbestiform and nonasbestiform tremolite into hamsters. Two samples contained 50 percent and 90 percent nonasbestiform tremolite, one sample contained acicular tremolite cleavage fragments, and two samples were asbestiform. No tumors were observed with the primarily nonasbestiform tremolite samples. Tumors were observed with the asbestiform samples. Wagner et al. (1969, 1982) injected two nonasbestiform and one asbestiform tremolite samples into the pleural cavity of rats. Tumors were observed with asbestiform tremolite samples. No tumors were observed with the nonasbestiform tremolite samples.

Finally, Stanton (1981) implanted two talc samples that contained 30 percent to 50 percent nonasbestiform tremolite into the pleural cavities of rats and observed no excess tumors with these samples.

In summary, the health community appears to be split as to the risk that exposure to nonasbestiform amphiboles poses. The lack of control over factors other than exposure to amphiboles, such as smoking history, appears to confound data interpretation. The results of animal studies, however, suggest that the nonasbestiform amphiboles may not be health hazards. Because arguments can be made both for and against health risks associated with exposure to nonasbestiform amphiboles, there is an obvious need for further study in this area. To date, therefore, OSHA has not conclusively demonstrated a health risk associated with nonasbestiform amphiboles.

AT&A in the Workplace

To investigate the extent to which OSHA had measured levels of AT&A in the workplace, and therefore whether the agency had met its mandate of finding a perceived risk before promulgating its regulation, the Bureau of Mines formally requested OSHA inspection data from 11 four-digit industry SIC codes representing industries believed to handle material that could contain AT&A.[3] The data received represent OSHA's sampling effort for

[3]These industry SIC codes include Highway and Street Construction, Except Elevated Highways (SIC 1611), Bridge, Tunnel, and Elevated Highway Construction (1622), Paints, Varnishes, Lacquers, Enamels, and Allied Products (2851), Tires and Inner Tubes (3011), Concrete Block and Brick (3271), Concrete Products, Except Block and Brick (3272), Ready-Mixed Concrete (3273), Lime (3274), Steel Works, Blast Furnaces (Including Coke Ovens), and Rolling Mills (3312), Primary Smelting and Refining of Copper (3331), and Primary Smelting and Refining of Nonferrous Metals, Except Copper and Aluminum (3339).

"asbestos (all forms)" in these industries during the period October 1983 through April 1989. No personal samples,[4] which is the type required of employers under the provisions of the regulation, were taken in six of these industry groups: the two construction groups (SIC 1611 and 1622), ready-mixed concrete, lime, and the two smelting groups (SIC 3331 and 3339).

Only 47 personal samples were taken by OSHA in the five other industry groups over the five-year period. Of these samples, only five, or 11 percent, taken at 18 operations exceeded the action level of the proposed regulation. Two of the five samples were "ceiling" samples, which are measured over a 15-minute period instead of an eight-hour time-weighted average, and represent a short, perhaps sudden exposure rather than exposure over an eight-hour shift. In addition, at least one of the five samples that exceeded the action level was for asbestos, rather than AT&A.

In summary, OSHA has not fulfilled its mandate to conclusively demonstrate a health risk from AT&A before promulgating a regulation. The equivocal nature of the health literature and the inadequate amount of sampling done by OSHA in some industry groups where AT&A could be present render the benefits of such a regulation questionable at the present time.

[4] A personal sample is one in which a measuring device is attached to a worker over an eight-hour period to measure the worker's exposure during a work shift.

DEFINITION OF ASBESTOS

In its 1986 regulation, OSHA defined asbestos as "chrysotile, amosite, crocidolite, tremolite asbestos, anthophyllite asbestos, actinolite asbestos, and any of these minerals that have been chemically treated and/or altered" (51 Fed. Reg. 22733). This seemingly circular definition of "asbestos" as ". . . tremolite asbestos, anthophyllite asbestos, actinolite asbestos . . ." confounds the issue of what constitutes asbestos.

OSHA's definition of a fiber as "a particulate form of asbestos, tremolite, anthophyllite, or actinolite, 5 micrometers or longer, with a length-to-diameter ratio of at least 3 to 1" (51 Fed. Reg. 22733) is not consistent with its mineralogical definition of asbestos because nonasbestiform particles can be classified as asbestos given this definition.[5] Minerals such as feldspars, wollastonite, and pyroxenes typically cleave into fragments with aspect, or length-to-diameter, ratios of 3 to 1 or greater and will incorrectly be identified as AT&A based on aspect ratio alone. Additionally, these minerals will be identified as asbestos if only aspect ratio is used in OSHA's analytical procedure.

[5]OSHA added the aspect, or length-to-diameter, ratio criterion to its fiber definition to conform with the practices of NIOSH, the American Industrial Hygiene Association, and the U.S. Public Health Service. Use of the 3 to 1 aspect ratio originated in the United Kingdom when three asbestos manufacturers arbitrarily selected it to facilitate the counting of asbestos particles by optical microscopy (Dupré, 1984). This can work well in an environment characterized by a known sample population, such as a textile mill where asbestos is woven into cloth, but is extremely misleading in a less restricted environment such as mineral production where a greater variance of material types is common.

A mineralogically correct definition of asbestos according to Bureau of Mines experts is:

> a term applied to six naturally occurring serpentine- and amphibole-group minerals that are exploited commercially because they crystallize into long, thin, flexible fibers that are easily separable when crushed or processed, can be woven, are resistant to heat and chemical attack, and are good electrical insulators.
>
> The six serpentine- and amphibole-group minerals commonly referred to as asbestos are chrysotile, grunerite asbestos (amosite), riebeckite asbestos (crocidolite), anthophyllite asbestos, tremolite asbestos, and actinolite asbestos. When viewed under light microscopy, these asbestos particles typically possess aspect ratios ranging from 20:1 to 100:1 or higher for particles longer than 5 um and widths of 0.5 um or less and have two or more of the following characteristics: bundles of parallel fibers, fibers with splayed ends, matted masses of individual fibers, and curved fibers.

It follows from this mineralogical definition and the characteristics of asbestos that the 3 to 1 aspect ratio criterion alone should not be used to classify a particle as asbestos as suggested by OSHA in its final rule. In addition to aspect ratio, analysis of a sample should include a search for the presence of the characteristics listed above.

If OSHA decides to continue its practice of only considering aspect ratio, the 3 to 1 criterion is acceptable for phase contrast microscopy if it is applied to all occupational settings where asbestos, as defined above, is present in the crude form, where asbestos or asbestos-containing materials are intentionally used in a manufacturing process to enhance the properties of a product, and where asbestos-containing products are used or are being removed. The 3 to 1 aspect ratio is acceptable under these conditions because low aspect ratio fiber bundles frequently are observed in these occupational settings and a 3 to 1 aspect ratio has been demonstrated to ensure the health of workers encountering asbestos in the work environment. An aspect ratio criterion of 10 to 1 should be used under all other conditions because it has been shown to adequately distinguish between asbestiform and nonasbestiform amphibole particulates.

In its final rule, OSHA

> acknowledges that some particles with an aspect ratio of less than 10 to 1 or 5 to 1 are not asbestos fibers, but OSHA does not regard this as a deficiency in using the 3 to 1 definition. As noted, the 3 to 1 aspect ratio has been successfully used for years. In addition, changing the ratio to 5 to 1 or greater as suggested by some commenters, would mean that OSHA would have to change the quantitative risk assessment and feasibility findings (51 Fed. Reg. 22681).

Thus, OSHA apparently refused to remedy the definitional problem associated with its regulation because doing so would involve revising previous risk and feasibility analyses. The agency should therefore reconsider its use of the aspect ratio criterion and base its decision on factors other than convenience.

GENERAL ECONOMIC IMPACT ON THE MINERALS INDUSTRY OF THE OSHA REGULATION

In its final economic impact assessment, OSHA analyzed "primary manufacturing, secondary manufacturing, automotive brake and clutch repair, shipbuilding and ship repair, and construction" (51 Fed. Reg. 22650), applications that use chrysotile. However, the agency did not specifically address impacts on the minerals industry, whose products sometimes contain AT&A. By not doing so, OSHA may be unaware of potential unintended impacts of its asbestos standard. To contribute to more effective regulatory rulemaking, the Bureau of Mines has assessed these impacts, the results of which are presented below.

OSHA Jurisdiction

With few exceptions, the OSHA asbestos regulation does not apply to the mining industry because minerals producers are generally regulated by MSHA under the Federal Mine Safety and Health Act of 1977 (P.L. 95-164), or Mine Act. The minerals processing industry, however, is subject to the OSHA asbestos regulation under the authority of the Occupational Safety and Health Act of 1970 (P.L. 91-596), or OSH Act. In 1979 these two Department of Labor agencies settled jurisdictional matters emanating from their legislative mandates in an interagency agreement (44 Fed. Reg. 22827). The Mine Act, administered by MSHA, generally applies to mine sites and milling operations. The OSH Act governs mines and mills where provisions of the Mine Act do not cover or apply to occupational safety and health hazards on these sites, such as hospitals on mine sites, or where there are no MSHA standards relevant to a particular condition on a mine or mill site.

Milling processes regulated by MSHA include crushing, grinding, pulverizing, sizing, concentrating, washing, drying, roasting, pelletizing, sintering, evaporating, calcining, kiln treatment, sawing and cutting stone, heat expansion, retorting, leaching, and briquetting. Disputes regarding what constitutes milling are resolved between the two agencies to "reflect Congress' intention . . . of inclusion of a facility within the coverage of the Mine Act" (44 Fed. Reg. 22828).

OSHA authority applies to gypsum board plants, brick, clay pipe and refractory plants, ceramic plants, fertilizer products, asphalt-mixing plants, concrete ready-mix or batch plants, custom stone finishing, smelting, electrowinning, and refining.

Extent of the Impact

Despite the fact that the OSHA asbestos regulation does not pertain to mining and milling operations, it will affect the businesses that consume mine and mill products in their production processes. This includes major segments of the minerals industry, such as smelters, as well as other consumers of mineral products, such as ready-mix concrete plants. Bulk commodity transfer facilities such as receiving docks, port storage yards, barge terminals, and railroad freight yards could also be impacted by the regulation. Mineral producers must be concerned with the AT&A content of their products since consumers of mineral products will likely demand to know the AT&A content of the material they purchase from mineral producers to protect themselves against product liability suits.

The severity of the problem becomes evident upon consideration of the geology of the United States and the likelihood of the occurrence of

AT&A. AT&A may be found in hydrothermally altered igneous rocks and in metamorphic rocks, which constitute the bedrock of about 40 percent of the contiguous United States. In addition, weathering processes erode these rocks and transport AT&A, which then become part of the sedimentary rock record or persist in soils and dust (Dunn, 1989b).

Due to the widespread occurrence of AT&A, air samples taken in mines and manufacturing plants that use mineral products often show signs of AT&A; this is supported by MSHA analyses. Fifty two percent of 381 air samples taken at stone quarries and sand and gravel pits by MSHA contained AT&A in excess of the OSHA "action level" (0.1 fibers per cubic centimeter of air).[6] These levels were found at 45 percent of the 163 operations sampled (Bailey, 1988). As was described earlier, OSHA inspection data sharply contrast with MSHA data on AT&A air concentrations. The inadequate level of sampling done by OSHA makes it difficult to generalize and may be indicative of the agency's apparent lack of consideration of minerals-related issues in its asbestos rule making.

The minerals industry and its customers are faced with problems, costs, and uncertainties stemming from this neglect. Several specific problems deserve discussion. First, regulating some, but not all, nonasbestiform amphiboles does not make sense from a chemical and physical perspective.[7] Regulation of only three of these minerals results in

[6]MSHA's fiber definition is the same as OSHA's, but MSHA performs more detailed analytical work to determine the identity and physical characteristics of a fiber before issuing a citation for asbestos.

[7]Five nonasbestiform amphibole minerals that can occur in an asbestiform habit (actinolite, tremolite, anthophyllite, riebeckite, and cummingtonite-grunerite) are similar, being hydrous silicates with varying amounts of iron, magnesium, calcium, and sodium. They are also similar physically, exhibiting the typical amphibole cleavage pattern.

costly analytical procedures to determine the mineral identity and whether the mineral in question is regulated by OSHA. Second, OSHA's definition of a fiber and the method of counting fibers in a sample, as previously discussed, can cause materials other than AT&A to be counted in the analysis of a sample. This imposes an unnecessary regulatory burden on an operation. Third, triggering of the labelling requirement when the AT&A content of a product exceeds 0.1 percent by weight confounds the intent of the regulation, which is to limit the airborne concentration of the minerals. The sampling procedure that a mineral producer must carry out to certify that its product contains less than 0.1 percent AT&A is exceedingly complex and costly. The lack of a sampling guideline by the regulatory agency is one of the greatest contributors of uncertainty associated with the regulation.

In summary, mineral producers will be affected by the proposed OSHA regulation because they must inform their customers, who are directly regulated by OSHA, of the AT&A content of their products. Nonasbestiform amphiboles are very common in nature and occur in a variety of geologic environments. Consequently, a large number of U.S. mineral producers will have to sample and test their products. OSHA's lack of guidance on an acceptable bulk sampling procedure and its definition of a fiber, which can result in false-positive analytical results, have created confusion and uncertainties in the minerals industry.

ECONOMIC IMPACT ON THE AGGREGATES, TALC, AND IRON ORE AND STEEL INDUSTRIES

A more detailed analysis was undertaken to identify and quantify specific economic impacts of the OSHA regulation on the aggregates, talc, and iron ore and steel sectors. These industries were singled out by Bureau of Mines commodity specialists and industry experts as industries that could be considerably impacted by the regulation.

Methodology

Six possible cost categories were identified for analysis after considering flow diagrams for mining, milling, and post-mill processing and determining impact points likely to result from the requirements of the OSHA regulation for the aggregates, talc, and iron ore and steel industries. The cost categories include: product sampling and analysis; purchase of safety equipment (e.g., respirators), employee training, and medical surveillance; product liability and effects on company insurance coverage; changes in production methods and effects on production rates; sales losses and reduction in market share; and mine closures and bankruptcy.

Costs were estimated by the Bureau of Mines based on data obtained from the literature and from conversations with 82 experts in government, trade groups and unions, consultants and academia, and industry.[8] In all cases, it is assumed that the estimated costs represent the incremental impact of the regulation of AT&A. In other words, it is

[8] Of the 82 people contacted, 34 were from government (41 percent), nine from trade groups and unions (11 percent), seven from consulting firms and academia (nine percent), and 32 from industry (39 percent).

assumed that industry is already complying with the portion of the regulation that was not stayed and is, therefore, in effect.

The costs considered in the analysis are not necessarily additive because not all of them apply to all three industries studied and to the same degree (table 1). For example, the purchase of safety equipment,

Table 1. Cost increases resulting from the regulation, by industry

Cost Category	Industry		
	Aggregates	Talc	Iron Ore & Steel
Sampling and analysis	Y	Y	Y
Safety equipment, etc.	N	N	Y
Product liability	Y	Y	Y
Production methods/rates	U	U	U
Sales/market impacts	Y	Y	U
Closures/bankruptcy	Y	Y	U

Y Yes
N No
U Uncertain

employee training, and medical surveillance applies only to plants directly regulated by OSHA. Mines and mills would therefore not be impacted, but sintering plants and blast furnaces in the steel industry might be.

The necessity for product sampling and analysis differs between industries. In the aggregates industry, Bureau analysts concluded that pits and quarries would have to be extensively sampled in order to determine the AT&A content of their products, whereas talc producers would need to undertake only modest sampling programs if the stay is lifted.

Changes in production methods and effects on production rate, sales losses and reduction in market share, and mine closures and bankruptcy

were not explored in any detail for each of the three mineral sectors. However, maximum sales losses were approximated by estimating the number of firms that may be impacted by the regulation.

Product liability and effects on company insurance coverage are costs that cannot be quantitatively estimated, but are potentially very significant given the litigious nature of American society. For example, Manville Corp., a former asbestos producer that went into Chapter 11 bankruptcy due to the filing of about 30,000 asbestos claims against it, will pay an estimated $2.5 billion over the next 26 years to settle the claims. The ongoing experience of a domestic talc company also serves to illustrate the drastic nature of product liability costs. In a brief filed with the United States Court of Appeals for the District of Columbia Circuit on April 27, 1989, to lift the "abeyance pending agency reconsideration" and for "a stay pending judicial review," the company maintained that because the asbestos standard

> improperly treats nonasbestos minerals as if they were asbestos, [its] economic viability has been, and is continuing to be, undermined (and irreparably harmed) through lost customers, lost good will, and lost insurance coverage, as well as through the expense of having to defend itself against over 2,000 "asbestos" claims filed against it (R.T. Vanderbilt v. OSHA et al., 1989).

The fact that a company has lost its general liability insurance coverage and is a defendant in numerous personal injury cases as a result of a regulation, that is yet to be settled, dramatically demonstrates the potential severity of this impact on the minerals industry.

Impact on the Aggregates Industry

The aggregates industry consists of crushed stone and sand and gravel producers. Preliminary Bureau of Mines estimates indicate that crushed stone production totalled 1.22 billion short tons valued at $5.6 billion, f.o.b. plant, in 1988, up from 1.20 billion tons valued at $5.2 billion in 1987. In 1987, employment in the industry, not including office workers, was 68,645, according to MSHA (1988) statistics. In 1988, construction sand and gravel production reached an estimated 881 million tons valued at $3.1 billion, down from 896 million tons valued at $3.0 billion. In 1987, employment in the industry, not including office workers, stood at about 35,200.

Aggregates-producing operations would not be subject to the OSHA regulation because, as indicated earlier, MSHA inspects pits and quarries. Consumers of aggregates, however, would have to adhere to the regulation and would undoubtedly want to know the specific AT&A content of the products they use. It is assumed that the aggregates producers would have to inform their customers of the AT&A content of their products, presumably through a Material Safety Data Sheet.

Recent legislation indicates the degree to which aggregates producers could be held liable for the content of their products. For example, in 1986 a bill was introduced in the County Council of Prince George's County, Maryland "for the purpose of prohibiting the use of asbestos-bearing aggregate and providing that each supplier of aggregate shall be conclusively presumed to warrant it to be free of asbestos

content" (County Council of Prince George's County, Maryland, 1986; emphasis added).[9]

An analysis was done to estimate the sampling costs that crushed ston producers could incur in order to determine the AT&A content of their products.[10] Bureau of Mines analysts estimated that about 1,325 quarries, or one fourth of the quarries in the United States, would be impacted by the OSHA regulation given the geology of domestic crushed stone deposits and the likelihood that AT&A can be found in them. Bureau analysts also estimated that about 780 of these quarries, or 15 percent of all U.S. quarries, would need to have detailed testing (i.e., drilling) done. The cost of preliminary deposit evaluation and detailed testing of the 1,325 quarries was estimated by the Bureau at $173 million. Because of the substantial drilling costs involved, it is assumed that companies would amortize some of these expenditures. Selecting ten and twenty year periods for amortizing the two types of drilling programs assumed, and choosing a ten percent discount rate, the first-year cost to the industry would be $24 million. The annual cost for the next nine years would be $22 million.

[9]The bill, which was defeated due to a technicality, would have required that aggregates products contain less than one hundred parts per million by volume (i.e., 0.01 percent) of asbestos. Asbestos was defined as actinolite, amosite, anthophyllite, chrysotile, crocidolite, or tremolite. A task force convened by the County Executive deliberated the bill for eighteen months and concluded that only the asbestiform varieties of these minerals should be regulated. In addition, the task force grappled with the sampling requirements of regulating to the 0.01 percent level and questioned whether reliable and consistent measurements could be made on a satisfactory basis to enforce the regulation.

[10]See Appendix B for a more detailed explanation of the cost analysis.

The detailed testing component of the cost described above pertains only to 435 of the 1,325 quarries, or about nine percent of U.S. quarries. Of particular significance, the analysis indicates that the remaining 345 of the 780 quarries subject to detailed testing, or seven percent of all U.S. crushed stone quarries, would be financially unable to afford the costs of the required detailed testing because of their small size.[11] These quarries could be forced to shut down as a result of the burden imposed by the OSHA regulation. Stone production from these quarries in 1987 is estimated at 16.6 million tons valued at $72.5 million, f.o.b. plant.

Since the Bureau of Mines does not collect detailed information on the rock types that constitute sand and gravel deposits, the amount of AT&A in these deposits cannot readily be estimated. One expert suggested that, given the regulation, every sand and gravel deposit in the United States would have to be examined at least at a cursory level at a minimum cost of $1,000 per deposit (Dunn, 1989a). Since there are about 5,800 sand and gravel pits in the country, a minimum cost for sampling would be an estimated $5.8 million.

Losses in aggregates sales are possible and would depend on the availability and cost of material that is essentially free of AT&A as well as the potential legal liability associated with using products containing higher concentrations of these minerals. Given the regional nature of

[11]In the cost analysis, it was assumed that only impacted quarries producing in excess of 100,000 tons annually would be able to afford the cost associated with this activity (see Appendix B).

An estimated 44 percent of U.S. crushed stone quarries produced less than 100,000 tons in 1987.

aggregates markets and the significance of transportation cost to the final price, some areas could have to "import" aggregates from sources hundreds of miles from the market. Complex supply adjustments involving quarries, transportation routes and methods, and consumers would undoubtedly result in the long run. More severe market disruptions could occur in the short run as producers and consumers adjust to the regulation.

Impact on the Talc Industry

Talc was produced in ten states from 25 mines in 1988. Mine and mill employment stood at 980 workers. Geological and industry reports suggest that nonasbestiform amphiboles are present in trace to minor amounts in the working portions of six mines in four states, although it appears that five mines would be affected by the OSHA regulation. Approximately 351,005 tons of crude talc ore, valued at $5,199,000, were produced from these deposits in 1988. The estimated sales value of this ore was $20.8 million, or approximately 17 percent of total domestic talc sales of $119.5 million in 1988.

Most talc producers contacted by the Bureau did not indicate that they would test talc reserves to the extent that aggregate producers would. Therefore, sampling and analysis would be less costly for the talc industry than for the aggregates industry. Sampling and analysis for quality control and mine planning are routinely performed in the talc industry, and samples are analyzed for asbestos and AT&A because of the asbestos controversy. A wide variation in sampling and analysis programs was noted between companies, although most companies contacted could not quantify the costs of sampling and analysis because their mining costs are

not itemized. However, one company estimated analysis costs at approximately $200 per test. This company samples about three times a month. Another company collects and analyzes samples whenever drilling is performed prior to blasting. Drilling is performed on a 30-foot grid system. A third company performs sampling at the mine site, the primary crusher, the secondary crushers, and the bagging operations for quality control.

The major impact on the talc industry from the OSHA regulation would be a loss in sales from the five impacted mines. Bureau analysts estimate that a loss of about 60 percent of the sales of talc from these deposits, or about $12.3 million, could be expected over a period of a few years as consuming industries switched to alternative materials or AT&A-free talc. A minimum of 140 workers could be affected by the OSHA regulation. One producer stated that the OSHA regulation will force it to shut down its mine because of the loss of its customer base. Sales losses could also occur if talc consumers go out of business as a result of the OSHA regulation. CONSAD Research Corp. (1989) estimated that impacts on small companies, employing fewer than 20 workers, in industries such as sanitaryware, pottery products, and hobby slip manufacturing could be severe, with closures possible.

Some sales likely will be lost by the import market because imported talc would also have to be tested for AT&A. Imports accounted for eight percent of apparent domestic consumption in 1988, up from five percent in 1987. A loss in talc export sales of about 120,000 tons valued at $5.0 million could occur if labelling is required. This represents about 30 percent of total talc exports in 1988. Losses in talc import and

export sales would impact domestic transportation and distribution industries in addition to talc producers and consumers. For example, Bureau economists estimate that about 115 direct jobs would be lost in the transportation and wholesale industries if the above export sales loss occurs.

Tremolite, an AT&A mineral, is a desirable component of talc products in some applications. Consumers can expect higher prices for some varieties of sanitaryware, electrical ceramics, and paint if consuming industries decide to eliminate tremolitic talc from their products. The products will exhibit different characteristics during manufacturing and the manufacturing process will have to be modified to compensate for this change. For example, tremolitic talc is used in ceramics. Without tremolite in the formulation, the ceramic will exhibit different shrinkage, moisture adsorption, and firing characteristics. Producers will have to change their manufacturing process and, in some cases, the design of molds to compensate for these differences.

Impact on the Iron Ore and Steel Industries

Domestic iron ore shipments increased from 52.8 million short tons in 1987 to an estimated 67.3 million short tons in 1988. Nonasbestiform amphiboles are common in some of the U.S. iron ore mines. It is expected, however, that the OSHA regulation would not significantly impact the iron ore industry because almost all of the iron ore produced in the United States is pelletized (e.g., about 96 percent in 1987), a pyrometallurgical process that alters or destroys AT&A minerals. Iron ore is almost exclusively pelletized at the mine site, which is regulated by MSHA and therefore not subject to the OSHA regulation.

A number of mines sell direct shipping ore and concentrates for both steel and non-steel end uses, including cement, heavy media, specialty chemicals, agricultural products, pyrites, refractories, fluxes, and ballast. Sales of these products, if they contained AT&A, could be impacted by the OSHA regulation. It is estimated that at least eight of the 16 producers of direct shipping ore and concentrates in 1987 could be impacted by the OSHA regulation, given the geologic information available to the Bureau of Mines. Production of direct shipping ore and concentrates from these eight mines, which employed about 575 mine and mill workers, totalled about 1.9 million tons in 1987. Two of these mines produced iron ore pellets in addition to raw ore and concentrates; it is not known whether they would pelletize their ore in response to the OSHA regulation and incur the necessary associated costs or suffer sales losses significant enough to force closure. Two other iron ore mines included in the above estimate ceased production in 1988 for other reasons.

In the steel industry, which is inspected by OSHA, pig iron production rose from 48.3 million tons in 1987 to an estimated 56.9 million tons in 1988. Steel mill shipments increased from 76.7 million tons in 1987 to 86.0 million tons in 1988. Sinter plants and some blast furnaces use raw iron ore as feed. In 1987 blast furnaces used about 3 million tons of raw iron ore, which represented four percent of the feed material consumed (American Iron and Steel Institute, 1988). Sinter plants used 6.9 million tons of raw ore, 79 percent of which was imported (American Iron Ore Association, 1989). Blast furnaces and sinter plants that use raw ore and concentrates would probably sample feed material or require the mine to perform such sampling. Imported ores and concentrates also would have to be tested for AT&A; contractual arrangements between suppliers and

purchasers would determine how the sampling and analysis costs would be distributed. In addition, initial monitoring of employees at these plant would be the minimum cost incurred under the OSHA regulation.

ECONOMIC IMPLICATIONS OF THE POSSIBLE ADOPTION OF OSHA'S ASBESTOS REGULATION BY MSHA

OSHA has acknowledged that it is apparently the only governmental agency that regulates AT&A as asbestos (49 Fed. Reg. 14122). It is possible, however, that other regulatory agencies could follow OSHA's precedent in regulating AT&A as asbestos.[12] Industry sources have expressed concern that MSHA, OSHA's sister agency in the Department of Labor, may do so in the revision of its air quality regulations for mines.[13] The MSHA proposed rule, which is currently under review by the Office of Management and Budget, is due for release in the fall.

If MSHA does regulate AT&A as asbestos, the impact on the domestic minerals industry could be far more significant because AT&A is a common rock-forming mineral. Mines that extract AT&A, even as waste rock, would be affected. The impact on the aggregates industry would be much larger than that estimated earlier because producers would have to monitor their own employees and reduce AT&A levels to the mandated level.

[12]The asbestos definitions used by several other regulatory agencies are reviewed in Appendix.C.

[13]MSHA currently defines asbestos as "limited to the following minerals: chrysotile, amosite, crocidolite, anthophyllite asbestos, tremolite asbestos, and actinolite asbestos" (30 CFR §57.51(b)). The agency recognizes that processed or crushed asbestos separates into "flexible fibers made up of fibrils."

The domestic copper industry serves as another example of the potential impact of an MSHA regulation of AT&A as asbestos. The ten largest copper producers accounted for 82 percent of total copper mine capacity in 1987, and 80 percent and 79 percent, respectively, of copper mine and mill employment in the fourth quarter of 1987. Based on a review of the geologic literature and consultation with copper-deposit geology experts, it is concluded that four of the largest copper mines could be impacted if AT&A were regulated as asbestos. These four mines accounted for 31 percent of domestic copper mine production capacity in 1987, and 22 percent and 33 percent, respectively, of copper mine and mill employment in the fourth quarter of 1987. Although the economic impacts on these operations have not been estimated, they could be expected to be significant.

SUMMARY

The Occupational Safety and Health Administration has promulgated an asbestos regulation without adequately demonstrating a health risk, as required by the OSH Act of 1970 and a later Supreme Court ruling. This failure, coupled with the paucity of sample data collected at OSHA-regulated worksites where AT&A could be present and the low levels of "asbestos" in the samples that were taken indicate that there are no demonstrable net benefits which would result from the regulation and, therefore, makes the necessity of regulating AT&A doubtful.

OSHA's apparent lack of consideration of minerals-related issues in the formulation of its regulation is reflected in the rule itself, which contains internal inconsistencies due to definitional problems. The

agency's definition of a fiber and its procedure for sample analysis can erroneously lead to the classification of nonasbestiform materials, including AT&A, as asbestos. This leads to potentially significant product liability and insurance concerns and creates problems, costs, and uncertainties for the domestic minerals industry.

OSHA did not investigate the economic impact of its regulation on the domestic minerals industry, as evidenced by the industries covered in its final economic impact assessment. The regulation will impact the various sectors of the domestic minerals industry differently depending on the occurrence of AT&A in mineral deposits, whether AT&A is removed in processing, how customers react to the potential regulatory costs including the product liability issue, and how the producers themselves interpret the regulation given its ambiguities. The uncertainty and confusion created by the labelling requirement is obvious given aggregates producers' impression that they will have to extensively test their deposits, whereas talc producers have indicated that they will not be as rigorous in their sampling. The product liability concern is, perhaps, the issue that will cause the greatest impact on the minerals industry through lawsuits and supply adjustments to avoid suits.

The economic impact of the regulation is expected to be greatest on the aggregates industry, where producers have taken the product liability issue seriously, some having already sampled their deposits even though the regulation is still under administrative stay. It is expected that site visits and deposit sampling could cost the industry an estimated $22 million on an annualized basis and, additionally, could force up to seven percent of U.S. crushed stone quarries to close. Sales losses in

the aggregates industry are possible and would be contingent on the availability and cost of material that is essentially free of AT&A and the liability concerns associated with using products containing AT&A.

It is estimated that the domestic talc industry could lose up to $12 million in sales over a period of several years because of substitution arising from product liability concerns of consumers. The iron ore industry could lose sales of minor amounts of ore in the form of direct shipping ore and concentrates, and the steel industry would have to monitor exposed employees at sinter plants and at some blast furnaces.

The OSHA regulation will set a precedent that other regulatory agencies might follow. Treatment of AT&A as asbestos by other regulatory agencies could have a more widespread impact on the domestic minerals industry. It appears that the Environmental Protection Agency, Department of Transportation, and Consumer Product Safety Commission will not follow OSHA's lead in regulating AT&A as asbestos. However, the Mine Safety and Health Administration does not regulate AT&A as asbestos, but is currently revising its air quality regulations for mines. If the agency decides to go along with OSHA, the impact on the mining industry would be significant.

RECOMMENDATIONS TO OSHA

Based on the Bureau of Mines analysis, it is recommended that OSHA not regulate AT&A as asbestos unless medical data conclusively show that these minerals present a health risk which would be reduced through regulation. In the event that such a determination is made in the future based on

adequate data, the following recommendations are offered to OSHA so that the agency can more appropriately apply its regulation to the minerals industry:

(1) OSHA should revise its asbestos and fiber definitions, as suggested earlier, to make the two terms consistent from a mineralogical standpoint;

(2) OSHA should more extensively sample plants that use mineral products to determine whether and the extent to which employees are actually being exposed to AT&A and, therefore, whether there is a real need to regulate AT&A in OSHA-regulated worksites at all;

(3) OSHA should specifically address the relationship between the AT&A content of a product and the airborne concentration of AT&A;

(4) OSHA should issue sampling guidelines for minerals producers to resolve the confusion created by the labelling requirement; and

(5) OSHA should specifically address the economic impact of its proposed regulation on the minerals industry and weigh these costs against possible benefits before publishing its final standard in November 1990.

REFERENCES

1. American Iron and Steel Institute. Annual Statistical Report 1987. 1988, p. 74.

2. American Iron Ore Association. Iron Ore 1988. 1989, p. 38.

3. Bailey, K. F. Impact on Aggregates of Regulating Nonasbestos Minerals as Asbestos. Mining Engineering, v. 40, no. 11, 1988, pp. 1024-1030.

4. Brown, D.P., Kaplan, S.D., Zumwalde, R.D., Kaplowitz, M., and V.E. Archer. A Retrospective Cohort Mortality Study of Underground Gold Mine Workers. In Goldsmith, D.F., Wing, D.M., and C.M. Shy (Eds), Silica, Silicosis and Cancer: Controversy in Occupational Medicine. Philadelphia, Praeger, 1985a.

5. _____. A Retrospective Cohort Mortality Study of Underground Gold Mine Workers. NIOSH report, dated January, 1985b.

6. Brown, D. P. and J. K. Wagoner. Occupational Exposure to Talc Containing Asbestos, Part III: Retrospective Cohort Study of Mortality. NIOSH Pub. No. 80-115, 1980.

7. Chittai, S., J. R. Martin, E. Moore, J. Segovia, and D. C. F. Muir. Distribution of the ILO U/C categories (1980) for Pneumoconiosis in Two Iron Mines in Labrador West and Their Correlation to Measurement of Health and Exposure. Proc. VIIth International Pneumoconiosis Conference, Bochum, Germany, 1983, pp. 1098-1106.

8. Clark, T. F., V. A. Harrington, J. Asta, W. K. C. Morgan, et al. Respiratory Effects of Exposure to Dust in Taconite Mining and Processing. Am. Rev. Respir. Dis., v. 121, 1980, pp. 959-966.

9. CONSAD Research Corp. Economic Analysis of the Proposed Revision to the OSHA Standard Covering Occupational Exposure to Asbestos and

Nonasbestiform Fibers. Prepared for U.S. Department of Labor, Occupational Safety and Health Administration. Contract No. J-9-F-7-0052, 1989, 233 pp.

10. Cooper, W. C., O. Wong, and R. Graebner. An Updated Epidemiologic Study of Workers in Two Minnesota Taconite Mining and Milling Operations. Prepared for American Iron Ore Association, July 21, 1986.

11. County Council of Prince George's County, Maryland. Bill no. CB-20-1986. 1986, 3 pp.

12. Dunn Geosciences Corporation. Obtaining Quantitative Data from Stone Operations for OSHA Regulated Mineral Content. Contract report prepared for the National Stone Association. 1988, 20 pp.

13. Dunn, J. R. Chairman, Dunn Geosciences Corporation. Personal Communication, 1989a.

14. _____. Fibers and the Mining Industry, Geologic Occurrence of Mineral Fibers and Some Economic Consideration of Regulations. Paper presented at the Society of Mining Engineers/National Stone Association meeting "fibers, fibers, fibers" in Baltimore, Maryland, April 7, 1989. 1989b, 11 pp.

15. Dupré, J. S. Report of The Royal Commission on Matters of Health and Safety Arising from the Use of Asbestos in Ontario. V. 2. 1984, p. 373.

16. Edstrom, H. W. and K. M. D. Rice. Labrador Lung: An Unusual Mixed Dust Pneumoconiosis. Canadian Med. Assn. J., v. 126, 1982, pp. 27-30.

17. Federal Register, various issues.

18. Gamble, J. F., W. Fellner, and M. J. Dimeo. Respiratory Morbidity Among Miners and Millers of Asbestiform Talc. Chapter in Dusts and Disease: Proceedings of the Conference on Occupational Exposures to Fibrous and Particulate Dust and Their Extension into the Environment. Edited by R. Lemen and M. Dement., Pathodox Pub. 1979.

19. Gillam, J. D., J. M. Dement, R. A. Lemen, J. K. Wagoner, V. E. Archer, and H. R. Blejer. Mortality Patterns among Hard Rock Gold Miners Exposed to an Asbestiform Mineral. Ann. NY Acad. Sci., v. 271, 1976, pp. 336-344.

20. Higgins, I. T. T., J. H. Glassman, M. S. Oh, and R. G. Cornell. Mortality of Reserve Mine Company Employees in Relation to Taconite Dust Exposure. Am. J. Epidemiology, v. 118, 1983, pp. 710-719.

21. McDonald, J. C., G. W. Gibbs, F. D. K. Liddell, and A. D. McDonald. Mortality after Long Exposure to Cummingtonite-grunerite. Am. Rev. Resp. Dis., v. 118, 1978, pp. 271-177.

22. Mine Safety and Health Administration. Mine Injuries and Worktime, Quarterly. Closeout Edition 1987. Division of Mining Information Systems. 1988, p. 6.

23. Pott, F., F. Huth, and K. H. Friedrichs. Tumorigenic Effect of Fibrous Dusts in Experimental Animals. Environ. Health Perspect., v. 9, 1974, pp. 313-315.

24. Randall, N.R. Talc Treads Ill-Defined Waters of OSHA. Ceramic Industry. March 1989, pp. 25-27.

25. R. T. Vanderbilt Company, Inc., Petitioner, v. Occupational Safety and Health Administration, et al., Respondents. Motion of R. T. Vanderbilt Company, Inc. to Lift "Abeyance Pending Agency Reconsideration" and for a Stay Pending Judicial Review. United States Court of Appeals for the District of Columbia Circuit. No. 86-1415, April 27, 1989.

26. Smith, W. E., K. K. Hubert, H. J. Sobel, et al. Biologic Tests of Tremolite in Hamsters. Chapter in Dusts and Disease: Proceedings of the Conference on Occupational Exposures to Fibrous and Particulate Dust and Their Extension into the Environment. Edited by R. Lemen and M. Dement., Pathodox Pub. 1979.

27. Stanton, M. F., M. Layard, A. Tegeris, et al. Relation of Particle Dimension to Carcinogenicity in Amphibole Asbestoses and Other Fibrous Minerals. J. Nat. Cancer Inst., v. 67, no. 5, 1981, pp. 965-975.

28. Stille, W. T. and I. R. Tabershaw. The Mortality Experience of Upstate New York Talc Workers. J. Occup. Med., v. 24, no. 6, 1982, pp. 480-484.

29. Swent, L. W., G. R. Herrin, J. K. Waterland, and R. F. Bell. Mortality Pattern Among Hard Rock Gold Miners, A Critique. 1976.

30. Tepordei, V. V. Crushed Stone. BuMines Minerals Yearbook 1987. V. 1, 1989, 23 pp.

31. Wagner, J. C. et al. Biological Effects of Tremolite. Br. J. Cancer, v. 45, 1982, pp. 352-360.

32. _____. Mesotheliomas in Rats Following Inoculation with Asbestos. Br. J. Cancer, v. 23, 1969, p. 567.

APPENDIX A

PROVISIONS OF THE OSHA ASBESTOS REGULATION

In its 1986 Standard for General Industry,[14] OSHA established an action level for asbestos and AT&A of 0.1 fiber per cubic centimeter of air (f/cc) and a permissible exposure limit (PEL) of 0.2 f/cc, determined as an eight-hour time weighted average (TWA). This standard replaced the agency's 1972 PEL of 2 f/cc. In addition, the 1986 rule mandates that warning labels be "affixed to all raw materials, mixtures, scrap, waste, debris, and other products" containing asbestos and AT&A in accordance with OSHA's Hazard Communication standard, which requires labels unless the minerals are present in concentrations less than 0.1 percent by weight (51 Fed. Reg. 22736). The 1988 amendment to the 1986 final rules set an excursion limit (EL) of 1.0 f/cc over a 30-minute sampling period to further reduce a perceived health risk (53 Fed. Reg. 35610).

The regulation requires that employers of affected operations perform initial and semiannual monitoring of employees expected to be exposed to airborne concentrations of AT&A at or above the action level. One sample must be taken per job category per work shift. Initial monitoring can be excused if monitoring was done within a six-month period immediately prior to issuance of OSHA's final rule or if the employer can demonstrate that the standard will not be exceeded on the basis of "objective data."

If the action level or excursion level is exceeded, the following actions must be taken by the employer: air monitoring every six months,

[14] In its 1986 final rules, OSHA issued separate standards applying to workplaces in general industry, including maritime, and to construction worksites.

annual medical surveillance of affected employees, and employee information and training.

If the permissible exposure level (PEL) or excursion level (EL) is exceeded, employers are required to: (1) establish and implement a written program to reduce employee exposure; (2) establish regulated areas demarcated from the rest of workplace, marked by warning signs (i.e., hazard communication), and supply each person entering the regulated area with a respirator; (3) implement engineering controls and work practices (e.g., local exhaust ventilation, wet methods) to reduce exposure to the PEL and EL or, if not feasible, to the lowest levels achievable, supplemented by respirators; (4) issue protective work clothing and equipment (e.g., coveralls, gloves, head coverings) to workers; and (5) construct hygiene facilities, including clean changerooms, showers, lunchroom facilities (with positive-pressure filtered air supply).

APPENDIX B

COST ESTIMATE FOR CRUSHED STONE PRODUCERS

An estimate for the number of quarries that would incur costs to test for AT&A was based on the rock type associated with each quarry and the probability that AT&A can occur in each rock type (table B-1). For example, Dunn (1989a) estimated that there is a five percent chance that limestone and dolomite deposits can contain AT&A greater than or equal to 0.1 percent, the concentration that would trigger the labelling requirement. Multiplying this probability by the number of limestone and dolomite quarries yields the estimated number of impacted quarries producing this rock type. Assuming uniform production among quarries because the actual production distribution is not known, the expected production and value of production impacted by the regulation are obtained by multiplying the occurrence probability by the 1987 production and value of production. This was done for each rock type for which probabilities were available; 97 percent of 1987 production was represented using this method. It is estimated that 26 percent of the quarries would be impacted, representing 17 percent of 1987 production.

Sampling costs were based on a contract study done for the National Stone Association by Dunn Geosciences Corporation, a consulting company that specializes in aggregates and industrial minerals. For sedimentary rock quarries, it is expected that a field check and laboratory investigation would have to be performed at every impacted quarry. The estimated cost, assuming that AT&A occurs stratigraphically and is evenly distributed within particular rock layers, is $2,000 if the results are negative. If AT&A is found at a concentration close to 0.1 percent,

detailed testing in the form of drilling reserves would be necessary. Dunn Geosciences Corporation (1988) costed the drilling and analysis of a ten-year, 16-acre reserve at $90,000, and estimated that ten percent of the sedimentary rock quarries would incur this cost.

Every impacted igneous and metamorphic quarry would have to be field checked. Dunn Geosciences Corporation (1988) estimated that this would cost $500 and entail a brief site visit or a single sample analysis if AT&A was abundant in the deposit. Such a determination would make it unnecessary to conduct a drilling program because it would already be known that the quarry products would trigger the labelling requirement. Bureau experts suggested that both sampling and a field check would be carried out. Dunn's cost estimate was consequently raised to $1,000. Dunn estimated that 25 percent of the igneous and metamorphic rock quarries contain abundant AT&A and would not be subject to further testing.

Seventy five percent of the igneous and metamorphic rock quarries would need to have more detailed work done to determine whether the AT&A content is less than 0.1 percent. The costs would most likely be higher than for sedimentary deposits because AT&A would be more irregularly distributed throughout the deposit. Based on actual data from a company that recently drilled and analyzed the AT&A in a deposit, Dunn estimated the cost at $400,000. Since this cost was for a "modest-sized property," the number is used here as an average cost to provide an estimate of the impact on the industry. It is recognized that this will provide only an order-of-magnitude impact estimate.

In addition to the initial sampling of quarries, Dunn estimated that 65 percent of igneous and metamorphic rock quarries would have to monitor production on a continuous basis because of the nonuniform distribution of AT&A in such deposits. The capital cost of laboratory facilities was estimated by Dunn at about $52,000 and the annual operating cost at $146,000. Bureau experts disputed the notion that 65 percent of all igneous and metamorphic quarries would test the deposits continuously to such an extent. It is likely that only large quarries would be able to do so; for this reason the Bureau estimated that continuous monitoring would be done by 65 percent of igneous and metamorphic rock quarries having annual production in excess of 2 million tons.

The results of the analysis using the above costs are displayed in table B-2. The initial sampling costs are divided according to rock type. The number of impacted quarries is taken from table B-1 and multiplied by the percent of quarries subject to the type of sampling and the cost of sampling to yield a total industry cost. For example, a site visit and laboratory test is assumed to be performed at all of the 329 sedimentary quarries at a cost per quarry of $2,000. The total cost is therefore $658,000. It is assumed that all quarries, regardless of size, would expense this cost when it is incurred, so the total cost is treated as a first-year cost.

To estimate the number of quarries that would perform detailed testing (i.e., drilling), it was assumed that only impacted quarries that produce in excess of 100,000 tons annually would be able to afford the cost associated with this activity.[15] Because the Bureau of Mines reports

[15]The average price for crushed stone in 1988, $4.60 per ton, means that

data on the size of operations rather than the size of quarries,[16] it was necessary to estimate the number of impacted quarries producing greater than 100,000 tons from the number of operations producing this amount. The expected number of quarries impacted by the OSHA asbestos regulation that produce greater than 100,000 tons annually is therefore calculated as the product of the ratio of operations producing greater than 100,000 tons annually to the total number of operations (the "operation ratio") and the number of impacted quarries, presented in table B-1. The number of impacted quarries that would perform detailed testing is calculated by multiplying the operation ratio, the number of impacted quarries, and the percentage of these quarries expected to perform the testing.

Thus, the number of sedimentary rock quarries expected to perform detailed testing is 329 x (1933/3473) x 0.1, or 18 quarries (see table B-2). At a cost of $90,000 per quarry, the total cost would be $1.6 million. It is expected that this cost would be amortized rather than expensed in the first year. The annual cost over a ten-year period, chosen because the drilling is assumed to be for a ten-year reserve, at a ten percent discount rate is $264,000.

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total revenues for companies that produce under 100,000 tons would be less than $460,000. It is unlikely that quarries of this size would be able to obtain financing for a $90,000 or $400,000 sampling project, unless they are owned by large companies. Even a large company might balk at such a large cost given the small amount of production involved.

[16]An operation is defined as a business location that usually represents one pit or quarry and has a unique Bureau of Mines/MSHA identification number. Occasionally, several quarries, sometimes producing different rock types, may be covered under one identification number. The purpose of assigning these identification numbers is to identify distinct business units and their locations.

The cost calculations for igneous and metamorphic rock quarries is similar to that for sedimentary rock deposits, except the cost of detailed testing is amortized over 20 years instead of ten years because it was assumed that a 20-year reserve would be drilled. As was previously noted, continuous monitoring costs are applied to quarries with annual production in excess of 2 million tons. It is assumed that the number of operations producing at such a level correspond to the number of quarries. Further, it is estimated that of the 84 quarries producing 2 million tons or more annually, 25 percent produce igneous or metamorphic rock products. The number of quarries that would monitor continuously, therefore, is estimated at 84 x 0.25 x 0.65, or about 14 quarries. The capital cost of $728,000 (14 x $52,000) associated with setting up a laboratory is annualized over 20 years at a ten percent discount rate, yielding an annual cost of $86,000.

The total sampling and monitoring cost is the sum of the individual costs, or about $173 million. The first-year cost of $24 million is the sum of the costs that would be expensed in the first year and the cost amortized in the first year. The annualized cost of $22 million represents the annual cost amortized over the next nine years.

A summary of the number of quarries that would be impacted by the OSHA regulation is presented as table B-3. It is estimated that 26 percent of the 5,109 quarries that accounted for 97 percent of 1987 crushed stone production will be impacted by the regulation. About 15 percent of the 5,109 quarries will be subject to detailed testing. Significantly, about seven percent of the 5,109 quarries will be subject to detailed testing and will be financially unable to undertake the testing. Stone production

from these 346 quarries in 1987 is estimated at 16.6 million tons valued at $72.5 million, f.o.b. plant.[17]

[17]The size-range distribution of the 1,540 operations, and the percentage of this total in each category, that produced under 100,000 tons annually in 1987 is: 0-25,000 tons -- 764 operations (50 percent); 25,000-50,000 tons -- 331 operations (21 percent); 50,000-75,000 tons -- 248 operations (16 percent); and 75,000-100,000 tons -- 197 operations (13 percent).

Assuming that the size-range distribution of the 346 quarries producing under 100,000 tons annually is the same as that for operations, the number of quarries in each size-range category is: 0-25,000 tons -- 173 quarries; 25,000-50,000 tons -- 73 quarries; 50,000-75,000 tons -- 55 quarries; and 75,000-100,000 tons -- 45 quarries.

A weighted-average tonnage associated with the 346 quarries, assuming production at the maximum of each size class, is (173 quarries x 25,000 tons) + (73 quarries x 50,000 tons) + (55 quarries x 75,000 tons) + (45 quarries x 100,000 tons), or 16.6 million tons. The value of this material at the 1987 average price of $4.37 per ton, f.o.b. plant, is $72.5 million.

Table B-1. Impact on quarries, by rock type

Rock Type	(1) Number of Quarries in 1987 1/	(2) Production (1000 st) in 1987 1/	(3) Value ($ 1000) in 1987 1/	(4) Probability of >= 0.10% AT&A 2/	(5) Estimated Number of Impacted Quarries [(1)x(4)]	(6) Production Impacted (Expected) (1000 st) [(2)x(4)]	(7) Value Impacted (Expected) ($ 1000) [(3)x(4)]
SEDIMENTARY							
Limestone and dolomite	2617	841,104	3,456,617	0.05	131	42,055	172,831
Sandstone	495	27,096	129,135	0.40	198	10,838	51,654
METAMORPHIC							
Marble	51	5,576	62,335	0.90	46	5,018	56,102
Quartzite	28	5,399	28,799	0.65	18	3,509	18,719
Slate	10	2,330	14,258	0.05	1	117	713
IGNEOUS							
Granite	735	179,972	900,682	0.25	184	44,993	225,171
Traprock	813	103,413	505,187	0.90	732	93,072	454,668
Volcanic cinder and scoria	360	3,657	14,952	0.05	18	183	748
TOTAL	5109	3/ 1,168,547	5,111,965	NAp	1,327	199,785	980,605

NAp Not applicable
1/ Source: Tepordei (1989)
2/ Source: Dunn (1989a)
3/ represents 97 percent of total 1987 production

Table B-2. Sampling and monitoring costs

	Impacted Quarries 1/		Sampling/Monitoring Cost			
	Percent 2/	Number	Per Operation 2/ ($ 1000)	Total ($ 1000)	Annualized 3/ ($ 1000)	First Year ($ 1000)
INITIAL SAMPLING						
Sedimentary						
Site visit/lab test	100%	329	2	658		658
Detailed testing 4/	10%	18	90	1,620	264	264
Igneous/Metamorphic						
Site visit/lab test	100%	998	1	998		998
Detailed testing 4/	75%	417	400	166,800	19,592	19,592
CONTINUOUS MONITORING 5/	65%	14				
Capital			52	728	86	86
Operating			146	2,044	2,044	2,044
TOTAL				172,848	21,986	23,642

1/ impacted quarries as determined in table B-1 (column 5), unless otherwise noted

2/ Source: adapted from Dunn Geoscience Corp. (1988) estimates

3/ detailed testing costs for igneous/metamorphic deposits and continuous monitoring capital costs are annualized at 10 percent over 20 years; detailed testing costs for sedimentary deposits are annualized at 10 percent over 10 years

4/ assumed that this will be done by impacted quarries with annual production exceeding 100,000 st
- EXPECTED number of such QUARRIES is estimated as the product of the percentage of OPERATIONS with annual production exceeding 100,000 st (1933/3473) and the number of impacted quarries
- e.g., average number of impacted sedimentary QUARRIES with annual production exceeding 100,000 st equals (1933/3473) x 329, or 183

5/ of impacted igneous and metamorphic quarries with annual production exceeding 2 million st
- estimated that the 84 OPERATIONS with annual production exceeding 2 million st represents 84 QUARRIES
- estimated that about 25 percent of these quarries are igneous/metamorphic

Table B-3. Number of impacted quarries

	Sedimentary	Igneous/ Metamorphic	Total Impacted Quarries 1/	Percent of Total Quarries 2/
Number of Impacted Quarries	329	998	1,327	26.0%
Subject to Detailed Testing 3/	33	749	781	15.3%
>100,000 st	18	417	435	8.5%
=< 100,000 st 4/	15	332	346	6.8%

1/ Data may not add to totals shown due to independent rounding.
2/ 5,109 quarries; represents 97 percent of total 1987 production
3/ 10 percent of impacted sedimentary quarries, 75 percent of impacted igneous/metamorphic quarries
4/ assumed that these smaller quarries will be financially unable to perform detailed testing

APPENDIX C

ASBESTOS AND OTHER REGULATORY AGENCIES

Environmental Protection Agency

The Environmental Protection Agency (EPA) officially defines asbestos as "the asbestiform varieties of serpentine (chrysotile), riebeckite (crocidolite), cummingtonite-grunerite, anthophyllite, and actinolite-tremolite" (40 CFR §61.141). The agency's definition of a fiber and therefore the definition of "asbestiform" is equivocal. The EPA does use the fiber definition espoused by OSHA (i.e., aspect ratio greater than 3 to 1), but recognizes that the aspect ratio in "natural samples," or samples that have not been crushed, is much higher than 3 to 1. The morphology of asbestiform fibers is considered in sample analysis.

The EPA regulates asbestos under the Toxic Substances Control Act (TSCA), the Clean Water Act, and the National Emission Standards for Hazardous Air Pollutants (NESHAPS). There is, however, apparently no statutory requirement for each division within the agency to define asbestos identically. For example, despite the official agency definition, the only asbestos mineral regulated by the Effluent Guidelines Division (i.e., water regulations) is chrysotile. An agency official indicated that chrysotile is a form of asbestos that everybody agrees is asbestos and is a fiber that can be identified and counted fairly easily.

The apparent intent of EPA in regulating asbestos is not to include AT&A. The rule announced in July 1989 under TSCA to phase out the use of asbestos products lists products containing asbestos, such as

asbestos-cement pipe and asbestos clothing, and not AT&A, which has little or no commercial value and therefore is not used in products. Under its NESHAPS regulation, EPA is currently only inspecting public schools for asbestos.

Department of Transportation

The Department of Transportation (DOT) defines asbestos as "any of the following hydrated mineral silicates: chrysotile, crocidolite, amosite, anthophyllite asbestos, tremolite asbestos, and actinolite asbestos, and every product containing any of these minerals" (49 CFR §173.1090). The DOT does not incorporate OSHA rules in its regulations. The Sciences Branch Chief in the Department's Office of Hazardous Materials Transportation indicated that DOT would not regulate asbestos if it is not of commercial value or is in a fixed form (i.e., in a binder). In addition, DOT does not regulate AT&A.

Consumer Product Safety Commission

The Consumer Product Safety Commission (CPSC) defines asbestos as "a group of mineral fibers composed of hydrated silicates . . . [a]mosite, chrysotile, crocidolite, anthophyllite asbestos, actinolite asbestos, and tremolite asbestos" (16 CFR §1304.3(b)). Treatment of AT&A by the CPSC, at least with regard to nonasbestiform tremolite, is clear. In January 1989, the CPSC denied a petition filed by a New Jersey physician to ban consumer goods containing tremolite in excess of 0.01 percent in granular and pulverized limestone products. In its denial, the CPSC cited its review of the epidemiologic literature and its conclusion that nonasbestiform tremolite cleavage fragments do not pose a carcinogenic

health hazard. A program manager in the CPSC Office of Program Management and Budget said that the CPSC would deny other petitions concerning nonasbestiform tremolite as the result of its study, but would review the medical literature if petitions were filed regarding other AT&A minerals.

ATTACHMENT 3

Regulations (Standards - 29 CFR)

OSHA Reference Method - Mandatory - 1910.1001 App A

Regulations (Standards - 29 CFR) - Table of Contents

• **Part Number:**	1910
• **Part Title:**	Occupational Safety and Health Standards
• **Subpart:**	Z
• **Subpart Title:**	Toxic and Hazardous Substances
• **Standard Number:**	1910.1001 App A
• **Title:**	OSHA Reference Method - Mandatory

This mandatory appendix specifies the procedure for analyzing air samples for asbestos and specifies quality control procedures that must be implemented by laboratories performing the analysis. The sampling and analytical methods described below represent the elements of the available monitoring methods (such as Appendix B of thier regulation, the most current version of the OSHA method ID-160, or the most current version of the NIOSH Method 7400). All employers who are required to conduct air monitoring under paragraph (d) of the standard are required to utilize analytical laboratories that use this procedure, or an equivalent method, for collecting and analyzing samples.

[redacted]pling and Analytical Procedure

1. The sampling medium for air samples shall be mixed cellulose ester filter membranes. These shall be designated by the manufacturer as suitable for asbestos counting. See below for rejection of blanks.

2. The preferred collection device shall be the 25-mm diameter cassette with an open-faced 50-mm electrically conductive extension cowl. The 37-mm cassette may be used if necessary but only if written justification for the need to use the 37-mm filter cassette accompanies the sample results in the employee's exposure monitoring record. Do not reuse or reload cassettes for asbestos sample collection.

3. An air flow rate between 0.5 liter/min and 2.5 liters/min shall be selected for the 25-mm cassette. If the 37-mm cassette is used, an air flow rate between 1 liter/min and 2.5 liters/min shall be selected.

4. Where possible, a sufficient air volume for each air sample shall be collected to yield between 100 and 1,300 fibers per square millimeter on the membrane filter. If a filter darkens in appearance or if loose dust is seen on the filter, a second sample shall be started.

5. Ship the samples in a rigid container with sufficient packing material to prevent dislodging the collected fibers. Packing material that has a high electrostatic charge on its surface (e.g., [redacted]anded polystyrene) cannot be used because such material can cause loss of fibers to the [redacted] of the cassette.

6. Calibrate each personal sampling pump before and after use with a representative filter cassette installed between the pump and the calibration devices.

7. Personal samples shall be taken in the "breathing zone" of the employee (i.e., attached to or near the collar or lapel near the worker's face).

Fiber counts shall be made by positive phase contrast using a microscope with an 8 to 10 X eyepiece and a 40 to 45 X objective for a total magnification of approximately 400 X and a numerical aperture of 0.65 to 0.75. The microscope shall also be fitted with a green or blue filter.

9. The microscope shall be fitted with a Walton-Beckett eyepiece graticule calibrated for a field diameter of 100 micrometers (+/-2 micrometers).

10. The phase-shift detection limit of the microscope shall be about 3 degrees measured using the HSE phase shift test slide as outlined below.

a. Place the test slide on the microscope stage and center it under the phase objective.

b. Bring the blocks of grooved lines into focus.

NOTE: The slide consists of seven sets of grooved lines (ca. 20 grooves to each block) in descending order of visibility from sets 1 to 7, seven being the least visible. The requirements for asbestos counting are that the microscope optics must resolve the grooved lines in set 3 completely, although they may appear somewhat faint, and that the grooved lines in sets 6 and 7 must be invisible. Sets 4 and 5 must be at least partially visible but may vary slightly in visibility between microscopes. A microscope that fails to meet these requirements has either too low or too high a resolution to be used for asbestos counting.

If the image deteriorates, clean and adjust the microscope optics. If the problem persists, consult the microscope manufacturer.

11. Each set of samples taken will include 10 percent blanks or a minimum of 2 field blanks. These blanks must come from the same lot as the filters used for sample collection. The field blank results shall be averaged and subtracted from the analytical results before reporting. A set consists of any sample or group of samples for which an evaluation for this standard must be made. Any samples represented by a field blank having a fiber count in excess of the detection limit of the method being used shall be rejected.

12. The samples shall be mounted by the acetone/triacetin method or a method with an equivalent index of refraction and similar clarity.

13. Observe the following counting rules.

a. Count only fibers equal to or longer than 5 micrometers. Measure the length of curved fibers along the curve.

b. In the absence of other information, count all particles as asbestos that have a length-to-width ratio (aspect ratio) of 3:1 or greater.

c. Fibers lying entirely within the boundary of the Walton-Beckett graticule field shall receive a count of 1. Fibers crossing the boundary once, having one end within the circle, shall receive the count of one half (1/2). Do not count any fiber that crosses the graticule boundary more than once. Reject and do not count any other fibers even though they may be visible outside the graticule area.

d. Count bundles of fibers as one fiber unless individual fibers can be identified by observing both ends of an individual fiber.

e. Count enough graticule fields to yield 100 fibers. Count a minimum of 20 fields; stop counting at 100 fields regardless of fiber count.

14. Blind recounts shall be conducted at the rate of 10 percent.

Quality Control Procedures

1. Intralaboratory program. Each laboratory and/or each company with more than one microscopist counting slides shall establish a statistically designed quality assurance program involving blind recounts and comparisons between microscopists to monitor the variability of counting by each microscopist and between microscopists. In a company with more than one laboratory, the program shall include all laboratories and shall also evaluate the laboratory-to-laboratory variability.

2.a. Interlaboratory program. Each laboratory analyzing asbestos samples for compliance determination shall implement an interlaboratory quality assurance program that as a minimum includes participation of at least two other independent laboratories. Each laboratory shall participate in round robin testing at least once every 6 months with at least all the other laboratories in its interlaboratory quality assurance group. Each laboratory shall submit slides typical of its own work load for use in this program. The round robin shall be designed and results analyzed using appropriate statistical methodology.

2.b. All laboratories should also participate in a national sample testing scheme such as the Proficiency Analytical Testing Program (PAT), or the Asbestos Registry sponsored by the American Industrial Hygiene Association (AIHA).

3. All individuals performing asbestos analysis must have taken the NIOSH course for sampling and evaluating airborne asbestos dust or an equivalent course.

4. When the use of different microscopes contributes to differences between counters and laboratories, the effect of the different microscope shall be evaluated and the microscope shall be replaced, as necessary.

5. Current results of these quality assurance programs shall be posted in each laboratory to keep the microscopists informed.

[57 FR 24330, June 8, 1992; 59 FR 40964, Aug. 10, 1994]

Next Standard (1910.1001 App B)

Regulations (Standards - 29 CFR) - Table of Contents

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Occupational Safety & Health Administration
200 Constitution Avenue, NW
Washington, DC 20210

Regulations (Standards - 29 CFR)

Detailed procedure for asbestos sampling and analysis - Non-Mandatory - 1910.1001 App B

Regulations (Standards - 29 CFR) - Table of Contents

This OSHA method ID-160

phase-Contrast

• **Part Number:**	1910
• **Part Title:**	Occupational Safety and Health Standards
• **Subpart:**	Z
• **Subpart Title:**	Toxic and Hazardous Substances
• **Standard Number:**	1910.1001 App B
• **Title:**	Detailed procedure for asbestos sampling and analysis - Non-Mandatory

Appendix B to §1910.1001 -- Detailed Procedures for Asbestos Sampling and Analysis -- Non-Mandatory

Matrix:
OSHA Permissible Exposure Limits:
Time Weighted Average..... 0.1 fiber/cc
Excursion Level (30 minutes)..... 1.0 fiber/cc

Collection Procedure:
A known volume of air is drawn through a 25-mm diameter cassette containing a mixed-cellulose ester filter. The cassette must be equipped with an electrically conductive 50-mm extension cowl. The sampling time and rate are chosen to give a fiber density of between 100 to 1,300 fibers/mm(2) on the filter.

Recommended Sampling Rate..... 0.5 to 5.0 liters/minute (L/min)

Recommended Air Volumes:
Minimum..... 25 L
Maximum..... 2,400 L

Analytical Procedure: A portion of the sample filter is cleared and prepared for asbestos fiber counting by Phase Contrast Microscopy (PCM) at 400X.

Commercial manufacturers and products mentioned in this method are for descriptive use only and do not constitute endorsements by USDOL-OSHA. Similar products from other sources can be substituted.

1. Introduction

This method describes the collection of airborne asbestos fibers using calibrated sampling pumps with mixed-cellulose ester (MCE) filters and analysis by phase contrast microscopy (PCM). Some terms used are unique to this method and are defined below:

Asbestos: A term for naturally occurring fibrous minerals. Asbestos includes chrysotile, crocidolite, amosite (cummingtonite-grunerite asbestos), tremolite asbestos, actinolite asbestos, anthophyllite asbestos, and any of these minerals that have been chemically treated and/or altered. The precise chemical formulation of each species will vary with the location from which it was mined. Nominal compositions are listed:

```
Chrysotile.....  Mg(3)Si(2)O(5)(OH)(4)
Crocidolite.....  Na(2)Fe(3)(2)(+)Fe(2)(3)(+)Si(8)O(22)(OH)(2)
Amosite.....  (Mg,Fe)(7)Si(8)O(22)(OH)(2)
Tremolite-actinolite..  Ca(2)(Mg,Fe)(5)Si(8)O(22)(OH)(2)
Anthophyllite.....  (Mg,Fe)(7)Si(8)O(22)(OH)(2)
```

Asbestos Fiber: A fiber of asbestos which meets the criteria specified below for a fiber.

Aspect Ratio: The ratio of the length of a fiber to it's diameter (e.g. 3:1, 5:1 aspect ratios).

Cleavage Fragments: Mineral particles formed by comminution of minerals, especially those characterized by parallel sides and a moderate aspect ratio (usually less than 20:1).

Detection Limit: The number of fibers necessary to be 95% certain that the result is greater than zero.

Differential Counting: The term applied to the practice of excluding certain kinds of fibers from the fiber count because they do not appear to be asbestos.

Fiber: A particle that is 5 um or longer, with a length-to-width ratio of 3 to 1 or longer.

Field: The area within the graticule circle that is superimposed on the microscope image.

Set: The samples which are taken, submitted to the laboratory, analyzed, and for which, interim or final result reports are generated.

Tremolite, Anthophyllite, and Actinolite: The non-asbestos form of these minerals which meet the definition of a fiber. It includes any of these minerals that have been chemically treated and/or altered.

Walton-Beckett Graticule: An eyepiece graticule specifically designed for asbestos fiber counting. It consists of a circle with a projected diameter of 100 + or - 2 um (area of about 0.00785 mm(2)) with a crosshair having tic-marks at 3-um intervals in one direction and 5-um in the orthogonal direction. There are marks around the periphery of the circle to demonstrate the proper sizes and shapes of fibers. This design is reproduced in Figure 1. The disk is placed in one of the microscope eyepieces so that the design is superimposed on the field of view.

1.1. History

Early surveys to determine asbestos exposures were conducted using impinger counts of total dust with the counts expressed as million particles per cubic foot. The British Asbestos Research Council recommended filter membrane counting in 1969. In July 1969, the Bureau of Occupational Safety and Health published a filter membrane method for counting asbestos fibers in the United States. This method was refined by NIOSH and published as P & CAM 239. On May 29, 1971, OSHA specified filter membrane sampling with phase contrast counting for evaluation of asbestos exposures at work sites in the United States. The use of this technique was again required by OSHA in 1986. Phase contrast microscopy has continued

to be the method of choice for the measurement of occupational exposure to asbestos.

1.2. Principle

[illegible]r is drawn through a MCE filter to capture airborne asbestos fibers. A wedge shaped portion of the filter is removed, placed on a glass microscope slide and made transparent. A measured area (field) is viewed by PCM. All the fibers meeting defined criteria for asbestos are counted and considered a measure of the airborne asbestos concentration.

1.3. Advantages and Disadvantages

There are four main advantages of PCM over other methods:

(1) The technique is specific for fibers. Phase contrast is a fiber counting technique which excludes non-fibrous particles from the analysis.

(2) The technique is inexpensive and does not require specialized knowledge to carry out the analysis for total fiber counts.

(3) The analysis is quick and can be performed on-site for rapid determination of air concentrations of asbestos fibers.

(4) The technique has continuity with historical epidemiological studies so that estimates of expected disease can be inferred from long-term determinations of asbestos exposures.

The main disadvantage of PCM is that it does not positively identify asbestos fibers. Other [illegible]ers which are not asbestos may be included in the count unless differential counting is [illegible]formed. This requires a great deal of experience to adequately differentiate asbestos from non-asbestos fibers. Positive identification of asbestos must be performed by polarized light or electron microscopy techniques. A further disadvantage of PCM is that the smallest visible fibers are about 0.2 um in diameter while the finest asbestos fibers may be as small as 0.02 um in diameter. For some exposures, substantially more fibers may be present than are actually counted.

1.4. Workplace Exposure

Asbestos is used by the construction industry in such products as shingles, floor tiles, asbestos cement, roofing felts, insulation and acoustical products. Non-construction uses include brakes, clutch facings, paper, paints, plastics, and fabrics. One of the most significant exposures in the workplace is the removal and encapsulation of asbestos in schools, public buildings, and homes. Many workers have the potential to be exposed to asbestos during these operations.

About 95% of the asbestos in commercial use in the United States is chrysotile. Crocidolite and amosite make up most of the remainder. Anthophyllite and tremolite or actinolite are likely to be encountered as contaminants in various industrial products.

1.5. Physical Properties

[illegible]estos fiber possesses a high tensile strength along its axis, is chemically inert, non-combustible, and heat resistant. It has a high electrical resistance and good sound absorbing properties. It can be weaved into cables, fabrics or other textiles, and also matted into asbestos papers, felts, or mats.

2. Range and Detection Limit

2.1. The ideal counting range on the filter is 100 to 1,300 fibers/mm(2). With a Walton-Beckett graticule this range is equivalent to 0.8 to 10 fibers/field. Using NIOSH counting statistics, a count of 0.8 fibers/field would give an approximate coefficient of variation (CV) of 0.13.

2.2. The detection limit for this method is 4.0 fibers per 100 fields or 5.5 fibers/mm(2). This was determined using an equation to estimate the maximum CV possible at a specific concentration (95% confidence) and a Lower Control Limit of zero. The CV value was then used to determine a corresponding concentration from historical CV vs fiber relationships. As an example:

```
Lower Control Limit (95% Confidence) = AC - 1.645(CV)(AC)

Where:

AC = Estimate of the airborne fiber concentration (fibers/cc)
     Setting the Lower Control Limit = 0 and solving for CV:
0  = AC - 1.645(CV)(AC)
CV = 0.61

 This value was compared with CV vs. count curves. The count at which CV
= 0.61 for Leidel-Busch counting statistics or for an OSHA Salt Lake
Technical Center (OSHA-SLTC) CV curve (see Appendix A for further
information) was 4.4 fibers or 3.9 fibers per 100 fields, respectively.
Although a lower detection limit of 4 fibers per 100 fields is supported
by the OSHA-SLTC data, both data sets support the 4.5 fibers per 100
fields value.
```

3. Method Performance -- Precision and Accuracy

Precision is dependent upon the total number of fibers counted and the uniformity of the fiber distribution on the filter. A general rule is to count at least 20 and not more than 100 fields. The count is discontinued when 100 fibers are counted, provided that 20 fields have already been counted. Counting more than 100 fibers results in only a small gain in precision. As the total count drops below 10 fibers, an accelerated loss of precision is noted.

At this time, there is no known method to determine the absolute accuracy of the asbestos analysis. Results of samples prepared through the Proficiency Analytical Testing (PAT) Program and analyzed by the OSHA-SLTC showed no significant bias when compared to PAT reference values. The PAT samples were analyzed from 1987 to 1989 (N = 36) and the concentration range was from 120 to 1,300 fibers/mm$^{(2)}$.

4. Interferences

Fibrous substances, if present, may interfere with asbestos analysis.

Some common fibers are:

```
Fiberglass
Anhydrite
Mineral Fibers
Perlite Veins
Gypsum
Some Synthetic Fibers
```

Membrane Structures
Sponge Spicules
Diatoms
Microorganisms
Wollastonite

The use of electron microscopy or optical tests such as polarized light, and dispersion staining may be used to differentiate these materials from asbestos when necessary.

5. Sampling

5.1. Equipment

5.1.1. Sample assembly (The assembly is shown in Figure 3). Conductive filter holder consisting of a 25-mm diameter, 3-piece cassette having a 50-mm long electrically conductive extension cowl. Backup pad, 25-mm, cellulose. Membrane filter, mixed-cellulose ester (MCE), 25-mm, plain, white, 0.4 to 1.2-um pore size.

Notes:

1. Do not re-use cassettes.
2. Fully conductive cassettes are required to reduce fiber loss to the sides of the cassette due to electrostatic attraction.
3. Purchase filters which have been selected by the manufacturer for asbestos counting or analyze representative filters for fiber background before use. Discard the filter lot if more than 4 fibers/100 fields are found.
4. To decrease the possibility of contamination, the sampling system (filter-backup pad-cassette) for asbestos is usually preassembled by the manufacturer.
5. Other cassettes, such as the Bell-mouth, may be used within the limits of their validation.

5.1.2. Gel bands for sealing cassettes.

5.1.3. Sampling pump.

Each pump must be a battery operated, self-contained unit small enough to be placed on the monitored employee and not interfere with the work being performed. The pump must be capable of sampling at the collection rate for the required sampling time.

5.1.4. Flexible tubing, 6-mm bore.

5.1.5. Pump calibration.

Stopwatch and bubble tube/burette or electronic meter.

5.2. Sampling Procedure

5.2.1. Seal the point where the base and cowl of each cassette meet with a gel band or tape.

5.2.2. Charge the pumps completely before beginning.

5.2.3. Connect each pump to a calibration cassette with an appropriate length of 6-mm bore plastic tubing. Do not use luer connectors -- the type of cassette specified above has built-in adapters.

5.2.4. Select an appropriate flow rate for the situation being monitored. The sampling flow rate must be between 0.5 and 5.0 L/min for personal sampling and is commonly set between 1 and 2 L/min. Always choose a flow rate that will not produce overloaded filters.

5.2.5. Calibrate each sampling pump before and after sampling with a calibration cassette in-line (Note: This calibration cassette should be from the same lot of cassettes used for sampling). Use a primary standard (e.g. bubble burette) to calibrate each pump. If possible, calibrate at the sampling site.

Note: If sampling site calibration is not possible, environmental influences may affect the flow rate. The extent is dependent on the type of pump used. Consult with the pump manufacturer to determine dependence on environmental influences. If the pump is affected by temperature and pressure changes, correct the flow rate using the formula shown in the section "Sampling Pump Flow Rate Corrections" at the end of this appendix.

5.2.6. Connect each pump to the base of each sampling cassette with flexible tubing. Remove the end cap of each cassette and take each air sample open face. Assure that each sample cassette is held open side down in the employee's breathing zone during sampling. The distance from the nose/mouth of the employee to the cassette should be about 10 cm. Secure the cassette on the collar or lapel of the employee using spring clips or other similar devices.

5.2.7. A suggested minimum air volume when sampling to determine TWA compliance is 25 L. For Excursion Limit (30 min sampling time) evaluations, a minimum air volume of 48 L is recommended.

5.2.8. The most significant problem when sampling for asbestos is overloading the filter with non-asbestos dust. Suggested maximum air sample volumes for specific environments are:

Environment	Air vol. (L)
Asbestos removal operations (visible dust).....	100
Asbestos removal operations (little dust).....	240
Office environments.....	400 to 2,400

Caution: Do not overload the filter with dust. High levels of non-fibrous dust particles may obscure fibers on the filter and lower the count or make counting impossible. If more than about 25 to 30% of the field area is obscured with dust, the result may be biased low. Smaller air volumes may be necessary when there is excessive non-asbestos dust in the air.

While sampling, observe the filter with a small flashlight. If there is a visible layer of dust on the filter, stop sampling, remove and seal the cassette, and replace with a new sampling assembly. The total dust loading should not exceed 1 mg.

5.2.9. Blank samples are used to determine if any contamination has occurred during sample handling. Prepare two blanks for the first 1 to 20 samples. For sets containing greater than 20

samples, prepare blanks as 10% of the samples. Handle blank samples in the same manner as air samples with one exception: Do not draw any air through the blank samples. Open the blank cassette in the place where the sample cassettes are mounted on the employee. Hold it open for about 30 seconds. Close and seal the cassette appropriately. Store blanks for shipment with the sample cassettes.

5.2.10. Immediately after sampling, close and seal each cassette with the base and plastic plugs. Do not touch or puncture the filter membrane as this will invalidate the analysis.

5.2.11. Attach and secure a sample seal around each sample cassette in such a way as to assure that the end cap and base plugs cannot be removed without destroying the seal. Tape the ends of the seal together since the seal is not long enough to be wrapped end-to-end. Also wrap tape around the cassette at each joint to keep the seal secure.

5.3. Sample Shipment

5.3.1. Send the samples to the laboratory with paperwork requesting asbestos analysis. List any known fibrous interferences present during sampling on the paperwork. Also, note the workplace operation(s) sampled.

5.3.2. Secure and handle the samples in such that they will not rattle during shipment nor be exposed to static electricity. Do not ship samples in expanded polystyrene peanuts, vermiculite, paper shreds, or excelsior. Tape sample cassettes to sheet bubbles and place in a container that will cushion the samples in such a manner that they will not rattle.

5.3.3. To avoid the possibility of sample contamination, always ship bulk samples in separate shipping containers.

6. Analysis

6.1. Safety Precautions

6.1.1. Acetone is extremely flammable and precautions must be taken not to ignite it. Avoid using large containers or quantities of acetone. Transfer the solvent in a ventilated laboratory hood. Do not use acetone near any open flame. For generation of acetone vapor, use a spark free heat source.

6.1.2. Any asbestos spills should be cleaned up immediately to prevent dispersal of fibers. Prudence should be exercised to avoid contamination of laboratory facilities or exposure of personnel to asbestos. Asbestos spills should be cleaned up with wet methods and/ or a High Efficiency Particulate-Air (HEPA) filtered vacuum.

Caution: Do not use a vacuum without a HEPA filter -- It will disperse fine asbestos fibers in the air.

6.2. Equipment

6.2.1. Phase contrast microscope with binocular or trinocular head.

6.2.2. Widefield or Huygenian 10X eyepieces (Note: The eyepiece containing the graticule must be a focusing eyepiece. Use a 40X phase objective with a numerical aperture of 0.65 to 0.75).

6.2.3. Kohler illumination (if possible) with green or blue filter.

6.2.4. Walton-Beckett Graticule, type G-22 with 100 plus or minus 2 um projected diameter.

6.2.5. Mechanical stage.

A rotating mechanical stage is convenient for use with polarized light.

6.2.6. Phase telescope.

6.2.7. Stage micrometer with 0.01-mm subdivisions.

6.2.8. Phase-shift test slide, mark II (Available from PTR optics Ltd., and also McCrone).

6.2.9. Precleaned glass slides, 25 mm X 75 mm. One end can be frosted for convenience in writing sample numbers, etc., or paste-on labels can be used.

6.2.10. Cover glass #1 1/2.

6.2.11. Scalpel (#10, curved blade).

6.2.12. Fine tipped forceps.

6.2.13. Aluminum block for clearing filter (see Appendix D and Figure 4).

6.2.14. Automatic adjustable pipette, 100- to 500-uL.

6.2.15. Micropipette, 5 uL.

6.3. Reagents

6.3.1. Acetone (HPLC grade).

6.3.2. Triacetin (glycerol triacetate).

6.3.3. Lacquer or nail polish.

6.4. Standard Preparation

A way to prepare standard asbestos samples of known concentration has not been developed. It is possible to prepare replicate samples of nearly equal concentration. This has been performed through the PAT program. These asbestos samples are distributed by the AIHA to participating laboratories.

Since only about one-fourth of a 25-mm sample membrane is required for an asbestos count, any PAT sample can serve as a "standard" for replicate counting.

6.5. Sample Mounting

Caution: See Safety Precautions in Section 6.1. before proceeding. The objective is to produce samples with a smooth (non-grainy) background in a medium with a refractive index of approximately 1.46. The technique below collapses the filter for easier focusing and produces

permanent mounts which are useful for quality control and interlaboratory comparison.

An aluminum block or similar device is required for sample preparation.

6.5.1. Heat the aluminum block to about 70 deg. C. The hot block should not be used on any surface that can be damaged by either the heat or from exposure to acetone.

6.5.2. Ensure that the glass slides and cover glasses are free of dust and fibers.

6.5.3. Remove the top plug to prevent a vacuum when the cassette is opened. Clean the outside of the cassette if necessary. Cut the seal and/or tape on the cassette with a razor blade. Very carefully separate the base from the extension cowl, leaving the filter and backup pad in the base.

6.5.4. With a rocking motion cut a triangular wedge from the filter using the scalpel. This wedge should be one-sixth to one-fourth of the filter. Grasp the filter wedge with the forceps on the perimeter of the filter which was clamped between the cassette pieces. DO NOT TOUCH the filter with your finger. Place the filter on the glass slide sample side up. Static electricity will usually keep the filter on the slide until it is cleared.

6.5.5. Place the tip of the micropipette containing about 200 uL acetone into the aluminum block. Insert the glass slide into the receiving slot in the aluminum block. Inject the acetone into the block with slow, steady pressure on the plunger while holding the pipette firmly in place. Wait 3 to 5 seconds for the filter to clear, then remove the pipette and slide from the aluminum block.

6.5.6. Immediately (less than 30 seconds) place 2.5 to 3.5 uL of triacetin on the filter (Note: Waiting longer than 30 seconds will result in increased index of refraction and decreased contrast between the fibers and the preparation. This may also lead to separation of the cover slip from the slide).

6.5.7. Lower a cover slip gently onto the filter at a slight angle to reduce the possibility of forming air bubbles. If more than 30 seconds have elapsed between acetone exposure and triacetin application, glue the edges of the cover slip to the slide with lacquer or nail polish.

6.5.8. If clearing is slow, warm the slide for 15 min on a hot plate having a surface temperature of about 50 deg. C to hasten clearing. The top of the hot block can be used if the slide is not heated too long.

6.5.9. Counting may proceed immediately after clearing and mounting are completed.

6.6. Sample Analysis

Completely align the microscope according to the manufacturer's instructions. Then, align the microscope using the following general alignment routine at the beginning of every counting session and more often if necessary.

6.6.1. Alignment

(1) Clean all optical surfaces. Even a small amount of dirt can significantly degrade the image.

(2) Rough focus the objective on a sample.

(3) Close down the field iris so that it is visible in the field of view. Focus the image of the iris with the condenser focus. Center the image of the iris in the field of view.

(4) Install the phase telescope and focus on the phase rings. Critically center the rings. Misalignment of the rings results in astigmatism which will degrade the image.

(5) Place the phase-shift test slide on the microscope stage and focus on the lines. The analyst must see line set 3 and should see at least parts of 4 and 5 but, not see line set 6 or 6. A microscope/microscopist combination which does not pass this test may not be used.

6.6.2. Counting Fibers

(1) Place the prepared sample slide on the mechanical stage of the microscope. Position the center of the wedge under the objective lens and focus upon the sample.

(2) Start counting from one end of the wedge and progress along a radial line to the other end (count in either direction from perimeter to wedge tip). Select fields randomly, without looking into the eyepieces, by slightly advancing the slide in one direction with the mechanical stage control.

(3) Continually scan over a range of focal planes (generally the upper 10 to 15 um of the filter surface) with the fine focus control during each field count. Spend at least 5 to 15 seconds per field.

(4) Most samples will contain asbestos fibers with fiber diameters less than 1 um. Look carefully for faint fiber images. The small diameter fibers will be very hard to see. However, they are an important contribution to the total count.

(5) Count only fibers equal to or longer than 5 um. Measure the length of curved fibers along the curve.

(6) Count fibers which have a length to width ratio of 3:1 or greater.

(7) Count all the fibers in at least 20 fields. Continue counting until either 100 fibers are counted or 100 fields have been viewed; whichever occurs first. Count all the fibers in the final field.

(8) Fibers lying entirely within the boundary of the Walton-Beckett graticule field shall receive a count of 1. Fibers crossing the boundary once, having one end within the circle shall receive a count of 1/2. Do not count any fiber that crosses the graticule boundary more than once. Reject and do not count any other fibers even though they may be visible outside the graticule area. If a fiber touches the circle, it is considered to cross the line.

(9) Count bundles of fibers as one fiber unless individual fibers can be clearly identified and each individual fiber is clearly not connected to another counted fiber. See Figure 1 for counting conventions.

(10) Record the number of fibers in each field in a consistent way such that filter non-uniformity can be assessed.

(11) Regularly check phase ring alignment.

(12) When an agglomerate (mass of material) covers more than 25% of the field of view,

reject the field and select another. Do not include it in the number of fields counted.

(13) Perform a "blind recount" of 1 in every 10 filter wedges (slides). Re-label the slides using a person other than the original counter.

6.7. Fiber Identification

As previously mentioned in Section 1.3., PCM does not provide positive confirmation of asbestos fibers. Alternate differential counting techniques should be used if discrimination is desirable. Differential counting may include primary discrimination based on morphology, polarized light analysis of fibers, or modification of PCM data by Scanning Electron or Transmission Electron Microscopy.

A great deal of experience is required to routinely and correctly perform differential counting. It is discouraged unless it is legally necessary. Then, only if a fiber is obviously not asbestos should it be excluded from the count. Further discussion of this technique can be found in reference 8.10.

If there is a question whether a fiber is asbestos or not, follow the rule:

"WHEN IN DOUBT, COUNT."

6.8. Analytical Recommendations -- Quality Control System

6.8.1. All individuals performing asbestos analysis must have taken the NIOSH course for sampling and evaluating airborne asbestos or an equivalent course.

6.8.2. Each laboratory engaged in asbestos counting shall set up a slide trading arrangement with at least two other laboratories in order to compare performance and eliminate inbreeding of error. The slide exchange occurs at least semiannually. The round robin results shall be posted where all analysts can view individual analyst's results.

6.8.3. Each laboratory engaged in asbestos counting shall participate in the Proficiency Analytical Testing Program, the Asbestos Analyst Registry or equivalent.

6.8.4. Each analyst shall select and count prepared slides from a "slide bank". These are quality assurance counts. The slide bank shall be prepared using uniformly distributed samples taken from the workload. Fiber densities should cover the entire range routinely analyzed by the laboratory. These slides are counted blind by all counters to establish an original standard deviation. This historical distribution is compared with the quality assurance counts. A counter must have 95% of all quality control samples counted within three standard deviations of the historical mean. This count is then integrated into a new historical mean and standard deviation for the slide.

The analyses done by the counters to establish the slide bank may be used for an interim quality control program if the data are treated in a proper statistical fashion.

7. CALCULATIONS

7.1. Calculate the estimated airborne asbestos fiber concentration on the filter sample using the following formula:

Where:

AC = Airborne fiber concentration

(For Equation A, Click Here)

[redacted] = Total number of fibers greater than 5 um counted
[redacted] = Total number of fields counted on the filter
BFB = Total number of fibers greater than 5 um counted in the blank
BFL = Total number of fields counted on the blank
ECA = Effective collecting area of filter (385 mm(2) nominal for a 25-mm filter.)
FR = Pump flow rate (L/min)
MFA = Microscope count field area (mm(2)). This is 0.00785 mm(2) for a Walton-Beckett Graticule.
T = Sample collection time (min)
1,000 = Conversion of L to cc

Note: The collection area of a filter is seldom equal to 385 mm(2). It is appropriate for laboratories to routinely monitor the exact diameter using an inside micrometer. The collection area is calculated according to the formula:

Area = pi(d/2)(2)

7.2. Short-cut Calculation

Since a given analyst always has the same interpupillary distance, the number of fields per filter for a particular analyst will remain constant for a given size filter. The field size for that analyst is constant (i.e. the analyst is using an assigned microscope and is not changing the [redacted]le).

For example, if the exposed area of the filter is always 385 mm(2) and the size of the field is always 0.00785 mm(2), the number of fields per filter will always be 49,000. In addition it is necessary to convert liters of air to cc. These three constants can then be combined such that ECA/(1,000 X MFA) = 49. The previous equation simplifies to:

(For Equation B, Click Here)

7.3. Recount Calculations

As mentioned in step 13 of Section 6.6.2., a "blind recount" of 10% of the slides is performed. In all cases, differences will be observed between the first and second counts of the same filter wedge. Most of these differences will be due to chance alone, that is, due to the random variability (precision) of the count method. Statistical recount criteria enables one to decide whether observed differences can be explained due to chance alone or are probably due to systematic differences between analysts, microscopes, or other biasing factors.

The following recount criterion is for a pair of counts that estimate AC in fibers/cc. The criterion is given at the type-I error level. That is, there is 5% maximum risk that we will reject a pair of counts for the reason that one might be biased, when the large observed difference is really due to chance.

[redacted]ject a pair of counts if:

(For Equation C, Click Here)

Where:

AC1 = lower estimated airborne fiber concentration
AC2 = higher estimated airborne fiber concentration
ACavg = average of the two concentration estimates
CV(FB) = CV for the average of the two concentration estimates

If a pair of counts are rejected by this criterion then, recount the rest of the filters in the submitted set. Apply the test and reject any other pairs failing the test. Rejection shall include a memo to the industrial hygienist stating that the sample failed a statistical test for homogeneity and the true air concentration may be significantly different than the reported value.

7.4. Reporting Results

Report results to the industrial hygienist as fibers/cc. Use two significant figures. If multiple analyses are performed on a sample, an average of the results is to be reported unless any of the results can be rejected for cause.

8. References

8.1. Dreesen, W.C., et al, U.S. Public Health Service: A Study of Asbestosis in the Asbestos Textile Industry, (Public Health Bulletin No. 241), US Treasury Dept., Washington, DC, 1938.

8.2. Asbestos Research Council: The Measurement of Airborne Asbestos Dust by the Membrane Filter Method (Technical Note), Asbestos Research Council, Rockdale, Lancashire, Great Britain, 1969.

8.3. Bayer, S.G., Zumwalde, R.D., Brown, T.A., Equipment and Procedure for Mounting Millipore Filters and Counting Asbestos Fibers by Phase Contrast Microscopy, Bureau of Occupational Health, U.S. Dept. of Health, Education and Welfare, Cincinnati, OH, 1969.

8.4. NIOSH Manual of Analytical Methods, 2nd ed., Vol. 1 (DHEW/ NIOSH Pub. No. 77-157-A). National Institute for Occupational Safety and Health, Cincinnati, OH, 1977. pp. 239-1-239-21.

8.5. Asbestos, Code of Federal Regulations 29 CFR 1910.1001. 1971.

8.6. Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite. Final Rule, Federal Register 51:119 (20 June 1986). pp. 22612-22790.

8.7. Asbestos, Tremolite, Anthophyllite, and Actinolite, Code of Federal Regulations 1910.1001. 1988. pp 711-752.

8.8. Criteria for a Recommended Standard -- Occupational Exposure to Asbestos (DHEW/NIOSH Pub. No. HSM 72-10267), National Institute for Occupational Safety and Health NIOSH, Cincinnati,OH, 1972. pp. III-1-III-24.

Leidel, N.A., Bayer,S.G., Zumwalde, R.D.,Busch, K.A., USPHS/NIOSH Membrane Filter Method for Evaluating Airborne Asbestos Fibers (DHEW/NIOSH Pub. No. 79-127). National Institute for Occupational Safety and Health, Cincinnati, OH, 1979.

8.10. Dixon, W.C., Applications of Optical Microscopy in Analysis of Asbestos and Quartz, Analytical Techniques in Occupational Health Chemistry, edited by D.D. Dollberg and A.W. Verstuyft. Wash. D.C.: American Chemical Society, (ACS Symposium Series 120) 1980. pp. 13-41.

Quality Control

The OSHA asbestos regulations require each laboratory to establish a quality control program. The following is presented as an example of how the OSHA-SLTC constructed its internal CV curve as part of meeting this requirement. Data is from 395 samples collected during OSHA compliance inspections and analyzed from October 1980 through April 1986.

Each sample was counted by 2 to 5 different counters independently of one another. The standard deviation and the CV statistic was calculated for each sample. This data was then plotted on a graph of CV vs. fibers/mm(2). A least squares regression was performed using the following equation:

```
CV = antilog1(10)[A(log(10)(x))(2)+B(log(10)(x))+C]

where:

 x = the number of fibers/mm(2)

Application of least squares gave:

 A = 0.182205
 B = -0.973343
 C = 0.327499

Using these values, the equation becomes:

 CV = antilog(10)[0.182205(log(10)(x))(2)-0.973343(log(10)(x))+0.327499]
```

Sampling Pump Flow Rate Corrections

This correction is used if a difference greater than 5% in ambient temperature and/or pressure is noted between calibration and sampling sites and the pump does not compensate for the differences.

```
(For Equation D, Click Here)

Where:

Q(act) = actual flow rate
Q(cal) = calibrated flow rate (if a rotameter was used, the rotameter
         value)
P(cal) = uncorrected air pressure at calibration
P(act) = uncorrected air pressure at sampling site
T(act) = temperature at sampling site (K)
T(cal) = temperature at calibration (K)
```

Walton-Beckett Graticule

When ordering the Graticule for asbestos counting, specify the exact disc diameter needed to fit the ocular of the microscope and the diameter (mm) of the circular counting area.

Instructions for measuring the dimensions necessary are listed:

(1) Insert any available graticule into the focusing eyepiece and focus so that the graticule lines are sharp and clear.

(2) Align the microscope.

(3) Place a stage micrometer on the microscope object stage and focus the microscope on the graduated lines.

(4) Measure the magnified grid length, PL (um), using the stage micrometer.

(5) Remove the graticule from the microscope and measure its actual grid length, AL (mm). This can be accomplished by using a mechanical stage fitted with verniers, or a jeweler's loupe with a direct reading scale.

(6) Let D = 100 um. Calculate the circle diameter, d(c)(mm), for the Walton-Beckett graticule and specify the diameter when making a purchase:

$$d(c) = \frac{AL \times D}{PL}$$

Example: If PL = 108 um, AL = 2.93 mm and D = 100 um, then,

$$d(c) = \frac{2.93 \times 100}{108} = 2.71\text{mm}$$

(7) Each eyepiece-objective-reticle combination on the microscope must be calibrated. Should any of the three be changed (by zoom adjustment, disassembly, replacement, etc.), the combination must be recalibrated. Calibration may change if interpupillary distance is changed. Measure the field diameter, D (acceptable range: 100 plus or minus 2 um) with a stage micrometer upon receipt of the graticule from the manufacturer. Determine the field area (mm(2)).

Field Area = pi(D/2)(2)
If D = 100 um = 0.1 mm, then
Field Area = pi(0.1 mm/2)(2) = 0.00785 mm(2)

The Graticule is available from: Graticules Ltd., Morley Road, Tonbridge TN9 IRN, Kent, England (Telephone 011-44-732-359061). Also available from PTR Optics Ltd., 145 Newton Street, Waltham, MA 02154 [telephone (617) 891-6000] or McCrone Accessories and Components, 2506 S. Michigan Ave., Chicago, IL 60616 [phone (312)-842-7100]. The graticule is custom made for each microscope.

Counts for the Fibers in the Figure

Structure No.	Count	Explanation
1 to 6.....	1	Single fibers all contained within the circle.

7.....	1/2	Fiber crosses circle once.
8.....	0	Fiber too short.
9.....	2	Two crossing fibers.
10.....	0	Fiber outside graticule.
11.....	0	Fiber crosses graticule twice.
[redacted].....	1/2	Although split, fiber only crosses once.

(For Figure 1 of Walton-Beckett Graticule, Click Here)

[57 FR 24330, June 8, 1992; 59 FR 40964, Aug. 10, 1994; 60 FR 33972, June 29, 1995]

Next Standard (1910.1001 App C)

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Occupational Safety & Health Administration
200 Constitution Avenue, NW
Washington, DC 20210

ASBESTOS and OTHER FIBERS by PCM 7400

Various MW: Various CAS: Various RTECS: Various

METHOD: 7400, Issue 2 EVALUATION: FULL Issue 1: Rev. 3 on 15 May 1989
Issue 2: 15 August 1994

OSHA : 0.1 asbestos fiber (> 5 µm long)/cc;
1 f/cc/30 min excursion; carcinogen
MSHA: 2 asbestos fibers/cc
NIOSH: 0.1 f/cc (fibers > 5 µm long)/400 L; carcinogen
ACGIH: 0.2 crocidolite; 0.5 amosite; 2 chrysotile and other asbestos, fibers/cc; carcinogen

PROPERTIES: solid, fibrous, crystalline, anisotropic

SYNONYMS [CAS #]: actinolite [77536-66-4] or ferroactinolite [15669-07-5]; amosite [12172-73-5]; anthophyllite [77536-67-5]; chrysotile [12001-29-5]; serpentine [18786-24-8]; crocidolite [12001-28-4]; tremolite [77536-68-6]; amphibole asbestos [1332-21-4]; refractory ceramic fibers [142844-00-6]; fibrous glass.

SAMPLING

SAMPLER: FILTER (0.45- to 1.2-µm cellulose ester membrane, 25-mm; conductive cowl on cassette)

FLOW RATE*: 0.5 to 16 L/min

VOL-MIN*: 400 L @ 0.1 fiber/cc
-MAX*: (step 4, sampling)
*Adjust to give 100 to 1300 fiber/mm²

SHIPMENT: routine (pack to reduce shock)

SAMPLE STABILITY: stable

BLANKS: 2 to 10 field blanks per set

ACCURACY

RANGE STUDIED: 80 to 100 fibers counted

BIAS: See EVALUATION OF METHOD

OVERALL PRECISION ($\hat{S}_{rT}$):0.115 to 0.13 [1]

ACCURACY: See EVALUATION OF METHOD

MEASUREMENT

TECHNIQUE: LIGHT MICROSCOPY, PHASE CONTRAST

ANALYTE: fibers (manual count)

SAMPLE PREPARATION: acetone - collapse/triacetin - immersion

COUNTING RULES: described in previous version of this method as "A" rules [1,3]

EQUIPMENT:
1. positive phase-contrast microscope
2. Walton-Beckett graticule (100-µm field of view) Type G-22
3. phase-shift test slide (HSE/NPL)

CALIBRATION: HSE/NPL test slide

RANGE: 100 to 1300 fibers/mm² filter area

ESTIMATED LOD: 7 fibers/mm² filter area

PRECISION ($\hat{S}_r$): 0.10 to 0.12 [1]; see EVALUATION OF METHOD

APPLICABILITY: The quantitative working range is 0.04 to 0.5 fiber/cc for a 1000-L air sample. The LOD depends on sample volume and quantity of interfering dust, and is <0.01 fiber/cc for atmospheres free of interferences. The method gives an index of airborne fibers. It is primarily used for estimating asbestos concentrations, though PCM does not differentiate between asbestos and other fibers. Use this method in conjunction with electron microscopy (e.g., Method 7402) for assistance in identification of fibers. Fibers < ca. 0.25 µm diameter will not be detected by this method [4]. This method may be used for other materials such as fibrous glass by using alternate counting rules (see Appendix C).

INTERFERENCES: If the method is used to detect a specific type of fiber, any other airborne fiber may interfere since all particles meeting the counting criteria are counted. Chain-like particles may appear fibrous. High levels of non-fibrous dust particles may obscure fibers in the field of view and increase the detection limit.

OTHER METHODS: This revision replaces Method 7400, Revision #3 (date 5/15/89).

REAGENTS:

1. Acetone,* reagent grade.
2. Triacetin (glycerol triacetate), reagent grade.

* See SPECIAL PRECAUTIONS.

EQUIPMENT:

1. Sampler: field monitor, 25-mm, three-piece cassette with ca. 50-mm electrically conductive extension cowl and cellulose ester filter, 0.45- to 1.2-µm pore size, and backup pad.
   NOTE 1: Analyze representative filters for fiber background before use to check for clarity and background. Discard the filter lot if mean is ≥5 fibers per 100 graticule fields. These are defined as laboratory blanks. Manufacturer-provided quality assurance checks on filter blanks are normally adequate as long as field blanks are analyzed as described below.
   NOTE 2: The electrically conductive extension cowl reduces electrostatic effects. Ground the cowl when possible during sampling.
   NOTE 3: Use 0.8-µm pore size filters for personal sampling. The 0.45-µm filters are recommended for sampling when performing TEM analysis on the same samples. However, their higher pressure drop precludes their use with personal sampling pumps.
   NOTE 4: Other cassettes have been proposed that exhibit improved uniformity of fiber deposit on the filter surface, e.g., bellmouthed sampler (Envirometrics, Charleston, SC). These may be used if shown to give measured concentrations equivalent to sampler indicated above for the application.
2. Personal sampling pump, battery or line-powered vacuum, of sufficient capacity to meet flow-rate requirements (see step 4 for flow rate), with flexible connecting tubing.
3. Wire, multi-stranded, 22-gauge; 1", hose clamp to attach wire to cassette.
4. Tape, shrink- or adhesive-.
5. Slides, glass, frosted-end, pre-cleaned, 25 x 75-mm.
6. Cover slips, 22- x 22-mm, No. 1-1/2, unless otherwise specified by microscope manufacturer.
7. Lacquer or nail polish.
8. Knife, #10 surgical steel, curved blade.
9. Tweezers.

EQUIPMENT:

10. Acetone flash vaporization system for clearing filters on glass slides (see ref. [5] for specifications or see manufacturer's instructions for equivalent devices).
11. Micropipets or syringes, 5-µL and 100- to 500-µL.
12. Microscope, positive phase (dark) contrast, with green or blue filter, adjustable field iris, 8 to 10X eyepiece, and 40 to 45X phase objective (total magnification ca. 400X); numerical aperture = 0.65 to 0.75.
13. Graticule, Walton-Beckett type with 100-µm diameter circular field (area = 0.00785 mm2) at the specimen plane (Type G-22). Available from Optometrics USA, P.O. Box 699, Ayer, MA 01432 [phone (508)-772-1700], and McCrone Accessories and Components, 850 Pasquinelli Drive, Westmont, IL 60559 [phone (312) 887-7100].
    NOTE: The graticule is custom-made for each microscope. (see APPENDIX A for the custom-ordering procedure).
14. HSE/NPL phase contrast test slide, Mark II. Available from Optometrics USA (address above).
15. Telescope, ocular phase-ring centering.
16. Stage micrometer (0.01-mm divisions).

SPECIAL PRECAUTIONS: Acetone is extremely flammable. Take precautions not to ignite it. Heating of acetone in volumes greater than 1 mL must be done in a ventilated laboratory fume hood using a flameless, spark- free heat source.

SAMPLING:

1. Calibrate each personal sampling pump with a representative sampler in line.
2. To reduce contamination and to hold the cassette tightly together, seal the crease between the cassette base and the cowl with a shrink band or light colored adhesive tape. For personal sampling, fasten the (uncapped) open-face cassette to the worker's lapel. The open face should be oriented downward.
    NOTE: The cowl should be electrically grounded during area sampling, especially under conditions of low relative humidity. Use a hose clamp to secure one end of the wire (Equipment, Item 3) to the monitor's cowl. Connect the other end to an earth ground (i.e., cold water pipe).
3. Submit at least two field blanks (or 10% of the total samples, whichever is greater) for each set of samples. Handle field blanks in a manner representative of actual handling of associated samples in the set. Open field blank cassettes at the same time as other cassettes just prior to sampling. Store top covers and cassettes in a clean area (e.g., a closed bag or box) with the top covers from the sampling cassettes during the sampling period.
4. Sample at 0.5 L/min or greater [6]. Adjust sampling flow rate, Q (L/min), and time, t (min), to produce a fiber density, E, of 100 to 1300 fibers/mm^2 ($3.85 \cdot 10^4$ to $5 \cdot 10^5$ fibers per 25-mm filter with effective collection area A_c= 385 mm^2) for optimum accuracy. These variables are related to the action level (one-half the current standard), L (fibers/cc), of the fibrous aerosol being sampled by:

$$t = \frac{A_c \cdot E}{Q \cdot L \cdot 10^3}, \text{ min.}$$

NOTE 1: The purpose of adjusting sampling times is to obtain optimum fiber loading on the filter. The collection efficiency does not appear to be a function of flow rate in the range of 0.5 to 16 L/min for asbestos fibers [7]. Relatively large diameter fibers (>3 µm) may exhibit significant aspiration loss and inlet deposition. A sampling rate of 1 to 4 L/min for 8 h is appropriate in atmospheres containing ca. 0.1 fiber/cc in the absence of significant amounts of non-asbestos dust. Dusty atmospheres require smaller sample volumes (≤400 L) to obtain countable samples. In such cases take short, consecutive samples and average the results over the total collection time. For documenting episodic exposures, use high flow rates (7 to 16 L/min) over shorter sampling times. In relatively clean atmospheres, where targeted fiber concentrations are much less than 0.1 fiber/cc, use larger sample volumes (3000 to 10000 L) to achieve quantifiable loadings. Take care, however, not to overload the filter with background dust. If ≥ 50% of the filter surface is covered with particles, the filter may be too overloaded to count and will bias the measured fiber concentration.

NOTE 2: OSHA regulations specify a minimum sampling volume of 48 L for an excursion measurement, and a maximum sampling rate of 2.5 L/min [3].

5. At the end of sampling, replace top cover and end plugs.
6. Ship samples with conductive cowl attached in a rigid container with packing material to prevent jostling or damage.
   NOTE: Do not use untreated polystyrene foam in shipping container because electrostatic forces may cause fiber loss from sample filter.

SAMPLE PREPARATION:

NOTE 1: The object is to produce samples with a smooth (non-grainy) background in a medium with refractive index ≤1.46. This method collapses the filter for easier focusing and produces permanent (1 - 10 years) mounts which are useful for quality control and interlaboratory comparison. The aluminum "hot block" or similar flash vaporization techniques may be used outside the laboratory [2]. Other mounting techniques meeting the above criteria may also be used (e.g., the laboratory fume hood procedure for generating acetone vapor as described in Method 7400 - revision of 5/15/85, or the non-permanent field mounting technique used in P&CAM 239 [3,7,8,9]). Unless the effective filtration area is known, determine the area and record the information referenced against the sample ID number [1,9,10,11].

NOTE 2: Excessive water in the acetone may slow the clearing of the filter, causing material to be washed off the surface of the filter. Also, filters that have been exposed to high humidities prior to clearing may have a grainy background.

7. Ensure that the glass slides and cover slips are free of dust and fibers.
8. Adjust the rheostat to heat the "hot block" to ca. 70 °C [2].
   NOTE: If the "hot block" is not used in a fume hood, it must rest on a ceramic plate and be isolated from any surface susceptible to heat damage.
9. Mount a wedge cut from the sample filter on a clean glass slide.
   a. Cut wedges of ca. 25% of the filter area with a curved-blade surgical steel knife using a rocking motion to prevent tearing. Place wedge, dust side up, on slide.
      NOTE: Static electricity will usually keep the wedge on the slide.

b. Insert slide with wedge into the receiving slot at base of "hot block". Immediately place tip of a micropipet containing ca. 250 µL acetone (use the minimum volume needed to consistently clear the filter sections) into the inlet port of the PTFE cap on top of the "hot block" and inject the acetone into the vaporization chamber with a slow, steady pressure on the plunger button while holding pipet firmly in place. After waiting 3 to 5 sec for the filter to clear, remove pipet and slide from their ports.
   CAUTION: Although the volume of acetone used is small, use safety precautions. Work in a well-ventilated area (e.g., laboratory fume hood). Take care not to ignite the acetone. Continuous use of this device in an unventilated space may produce explosive acetone vapor concentrations.
c. Using the 5-µL micropipet, immediately place 3.0 to 3.5 µL triacetin on the wedge. Gently lower a clean cover slip onto the wedge at a slight angle to reduce bubble formation. Avoid excess pressure and movement of the cover glass.
   NOTE: If too many bubbles form or the amount of triacetin is insufficient, the cover slip may become detached within a few hours. If excessive triacetin remains at the edge of the filter under the cover slip, fiber migration may occur.
d. Mark the outline of the filter segment with a glass marking pen to aid in microscopic evaluation.
e. Glue the edges of the cover slip to the slide using lacquer or nail polish [12]. Counting may proceed immediately after clearing and mounting are completed.
   NOTE: If clearing is slow, warm the slide on a hotplate (surface temperature 50 °C) for up to 15 min to hasten clearing. Heat carefully to prevent gas bubble formation.

CALIBRATION AND QUALITY CONTROL:

10. Microscope adjustments. Follow the manufacturers instructions. At least once daily use the telescope ocular (or Bertrand lens, for some microscopes) supplied by the manufacturer to ensure that the phase rings (annular diaphragm and phase-shifting elements) are concentric. With each microscope, keep a logbook in which to record the dates of microscope cleanings and major servicing.
    a. Each time a sample is examined, do the following:
       (1) Adjust the light source for even illumination across the field of view at the condenser iris. Use Kohler illumination, if available. With some microscopes, the illumination may have to be set up with bright field optics rather than phase contract optics.
       (2) Focus on the particulate material to be examined.
       (3) Make sure that the field iris is in focus, centered on the sample, and open only enough to fully illuminate the field of view.
    b. Check the phase-shift detection limit of the microscope periodically for each analyst/microscope combination:
       (1) Center the HSE/NPL phase-contrast test slide under the phase objective.
       (2) Bring the blocks of grooved lines into focus in the graticule area.
          NOTE: The slide contains seven blocks of grooves (ca. 20 grooves per block) in descending order of visibility. For asbestos counting the microscope optics must completely resolve the grooved lines in block 3 although they may appear somewhat faint, and the grooved lines in blocks 6 and 7 must be invisible when centered in the graticule area. Blocks 4 and 5 must be at least partially visible but may vary slightly in visibility between microscopes. A microscope which fails to meet these requirements has resolution either too low or too high for fiber counting.
       (3) If image quality deteriorates, clean the microscope optics. If the problem persists, consult the microscope manufacturer.
11. Document the laboratory's precision for each counter for replicate fiber counts.
    a. Maintain as part of the laboratory quality assurance program a set of reference slides to be used on a daily basis [13]. These slides should consist of filter preparations including a range of loadings and background dust levels from a variety of sources including both field and reference samples (e.g., PAT, AAR, commercial samples). The Quality Assurance Officer

should maintain custody of the reference slides and should supply each counter with a minimum of one reference slide per workday. Change the labels on the reference slides periodically so that the counter does not become familiar with the samples.

b. From blind repeat counts on reference slides, estimate the laboratory intra- and intercounter precision. Obtain separate values of relative standard deviation (S_r) for each sample matrix analyzed in each of the following ranges: 5 to 20 fibers in 100 graticule fields, >20 to 50 fibers in 100 graticule fields, and >50 to 100 fibers in 100 graticule fields. Maintain control charts for each of these data files.

NOTE: Certain sample matrices (e.g., asbestos cement) have been shown to give poor precision [9]

12. Prepare and count field blanks along with the field samples. Report counts on each field blank.

NOTE 1: The identity of blank filters should be unknown to the counter until all counts have been completed.

NOTE 2: If a field blank yields greater than 7 fibers per 100 graticule fields, report possible contamination of the samples.

13. Perform blind recounts by the same counter on 10% of filters counted (slides relabeled by a person other than the counter). Use the following test to determine whether a pair of counts by the same counter on the same filter should be rejected because of possible bias: Discard the sample if the absolute value of the difference between the square roots of the two counts (in fiber/mm^2) exceeds 2.77 (X)S_r', where X = average of the square roots of the two fiber counts

(in fiber/mm^2) and $S_r' = \frac{S_r}{2}$, where S_r is the intracounter relative standard deviation for the

appropriate count range (in fibers) determined in step 11. For more complete discussions see reference [13].

NOTE 1: Since fiber counting is the measurement of randomly placed fibers which may be described by a Poisson distribution, a square root transformation of the fiber count data will result in approximately normally distributed data [13].

NOTE 2: If a pair of counts is rejected by this test, recount the remaining samples in the set and test the new counts against the first counts. Discard all rejected paired counts. It is not necessary to use this statistic on blank counts.

14. The analyst is a critical part of this analytical procedure. Care must be taken to provide a non-stressful and comfortable environment for fiber counting. An ergonomically designed chair should be used, with the microscope eyepiece situated at a comfortable height for viewing. External lighting should be set at a level similar to the illumination level in the microscope to reduce eye fatigue. In addition, counters should take 10-to-20 minute breaks from the microscope every one or two hours to limit fatigue [14]. During these breaks, both eye and upper back/neck exercises should be performed to relieve strain.
15. All laboratories engaged in asbestos counting should participate in a proficiency testing program such as the AIHA-NIOSH Proficiency Analytical Testing (PAT) Program for asbestos and routinely exchange field samples with other laboratories to compare performance of counters.

MEASUREMENT:

16. Center the slide on the stage of the calibrated microscope under the objective lens. Focus the microscope on the plane of the filter.
17. Adjust the microscope (Step 10).

NOTE: Calibration with the HSE/NPL test slide determines the minimum detectable fiber diameter (ca. 0.25 µm) [4].

18. Counting rules: (same as P&CAM 239 rules [1,10,11]: see examples in APPENDIX B).
    a. Count any fiber longer than 5 µm which lies entirely within the graticule area.
       (1) Count only fibers longer than 5 µm. Measure length of curved fibers along the curve.
       (2) Count only fibers with a length-to-width ratio equal to or greater than 3:1.
    b. For fibers which cross the boundary of the graticule field:
       (1) Count as 1/2 fiber any fiber with only one end lying within the graticule area, provided that the fiber meets the criteria of rule a above.

(2) Do not count any fiber which crosses the graticule boundary more than once.
(3) Reject and do not count all other fibers.

c. Count bundles of fibers as one fiber unless individual fibers can be identified by observing both ends of a fiber.
d. Count enough graticule fields to yield 100 fibers. Count a minimum of 20 fields. Stop at 100 graticule fields regardless of count.

19. Start counting from the tip of the filter wedge and progress along a radial line to the outer edge. Shift up or down on the filter, and continue in the reverse direction. Select graticule fields randomly by looking away from the eyepiece briefly while advancing the mechanical stage. Ensure that, as a minimum, each analysis covers one radial line from the filter center to the outer edge of the filter. When an agglomerate or bubble covers ca. 1/6 or more of the graticule field, reject the graticule field and select another. Do not report rejected graticule fields in the total number counted.

NOTE 1: When counting a graticule field, continuously scan a range of focal planes by moving the fine focus knob to detect very fine fibers which have become embedded in the filter. The small-diameter fibers will be very faint but are an important contribution to the total count. A minimum counting time of 15 seconds per field is appropriate for accurate counting.

NOTE 2: This method does not allow for differentiation of fibers based on morphology. Although some experienced counters are capable of selectively counting only fibers which appear to be asbestiform, there is presently no accepted method for ensuring uniformity of judgment between laboratories. It is, therefore, incumbent upon all laboratories using this method to report <u>total</u> fiber counts. If serious contamination from non-asbestos fibers occurs in samples, other techniques such as transmission electron microscopy must be used to identify the asbestos fiber fraction present in the sample (see NIOSH Method 7402). In some cases (i.e., for fibers with diameters >1 µm), polarized light microscopy (as in NIOSH Method 7403) may be used to identify and eliminate interfering non-crystalline fibers [15].

NOTE 3: Do not count at edges where filter was cut. Move in at least 1 mm from the edge.

NOTE 4: Under certain conditions, electrostatic charge may affect the sampling of fibers. These electrostatic effects are most likely to occur when the relative humidity is low (below 20%), and when sampling is performed near the source of aerosol. The result is that deposition of fibers on the filter is reduced, especially near the edge of the filter. If such a pattern is noted during fiber counting, choose fields as close to the center of the filter as possible [5].

NOTE 5: Counts are to be recorded on a data sheet that provides, as a minimum, spaces on which to record the counts for each field, filter identification number, analyst's name, date, total fibers counted, total fields counted, average count, fiber density, and commentary. Average count is calculated by dividing the total fiber count by the number of fields observed. Fiber density (fibers/mm^2) is defined as the average count (fibers/field) divided by the field (graticule) area (mm^2/field).

CALCULATIONS AND REPORTING OF RESULTS

20. Calculate and report fiber density on the filter, E (fibers/mm^2), by dividing the average fiber count per graticule field, F/n_f, minus the mean field blank count per graticule field, B/n_b, by the graticule field area, A_f (approx. 0.00785 mm^2):

$$E = \frac{\left(\frac{F}{n_f} - \frac{B}{n_b}\right)}{A_f}, \text{ fibers/mm}^2.$$

NOTE: Fiber counts above 1300 fibers/mm^2 and fiber counts from samples with >50% of filter area covered with particulate should be reported as "uncountable" or "probably biased." Other fiber counts outside the 100-1300 fiber/mm^2 range should be reported as having "greater than optimal variability" and as being "probably biased."

21. Calculate and report the concentration, C (fibers/cc), of fibers in the air volume sampled, V (L), using the effective collection area of the filter, A_c (approx. 385 mm^2 for a 25-mm filter):

$$C = \frac{(E)(A_c)}{V \cdot 10^3}.$$

NOTE: Periodically check and adjust the value of A_c, if necessary.

22. Report intralaboratory and interlaboratory relative standard deviations (from Step 11) with each set of results.

NOTE: Precision depends on the total number of fibers counted [1,16]. Relative standard deviation is documented in references [1,15-17] for fiber counts up to 100 fibers in 100 graticule fields. Comparability of interlaboratory results is discussed below. As a first approximation, use 213% above and 49% below the count as the upper and lower confidence limits for fiber counts greater than 20 (Fig. 1).

EVALUATION OF METHOD:

A. This method is a revision of P&CAM 239 [10]. A summary of the revisions is as follows:

1. Sampling:
   The change from a 37-mm to a 25-mm filter improves sensitivity for similar air volumes. The change in flow rates allows for 2-m^3 full-shift samples to be taken, providing that the filter is not overloaded with non-fibrous particulates. The collection efficiency of the sampler is not a function of flow rate in the range 0.5 to 16 L/min [10].
2. Sample Preparation Technique:
   The acetone vapor-triacetin preparation technique is a faster, more permanent mounting technique than the dimethyl phthalate/diethyl oxalate method of P&CAM 239 [2,4,10]. The aluminum "hot block" technique minimizes the amount of acetone needed to prepare each sample.
3. Measurement:
   a. The Walton-Beckett graticule standardizes the area observed [14,18,19].
   b. The HSE/NPL test slide standardizes microscope optics for sensitivity to fiber diameter [4,14].
   c. Because of past inaccuracies associated with low fiber counts, the minimum recommended loading has been increased to 100 fibers/mm^2 filter area (a total of 78.5 fibers counted in 100 fields, each with field area = .00785 mm^2.) Lower levels generally result in an overestimate of the fiber count when compared to results in the recommended analytical range [20]. The recommended loadings should yield intracounter S_r in the range of 0.10 to 0.17 [21,22,23].

B. Interlaboratory comparability:
An international collaborative study involved 16 laboratories using prepared slides from the asbestos cement, milling, mining, textile, and friction material industries [9]. The relative standard deviations (S_r) varied with sample type and laboratory. The ranges were:

	Intralaboratory S_r	Interlaboratory S_r	Overall S_r
AIA (NIOSH A Rules)*	0.12 to 0.40	0.27 to 0.85	0.46
Modified CRS (NIOSH B Rules)**	0.11 to 0.29	0.20 to 0.35	0.25

* Under AIA rules, only fibers having a diameter less than 3 µm are counted and fibers attached to particles larger than 3 µm are not counted. NIOSH A Rules are otherwise similar to the AIA rules.
** See Appendix C.

A NIOSH study conducted using field samples of asbestos gave intralaboratory S_r in the range 0.17 to 0.25 and an interlaboratory S_r of 0.45 [21]. This agrees well with other recent studies [9,14,16].

At this time, there is no independent means for assessing the overall accuracy of this method. One measure of reliability is to estimate how well the count for a single sample agrees with the mean count from a large number of laboratories. The following discussion indicates how this estimation can be carried out based on measurements of the interlaboratory variability, as well as showing how the results of this method relate to the theoretically attainable counting precision and to measured intra- and interlaboratory S_r. (NOTE: The following discussion does not include bias estimates and should not be taken to indicated that lightly loaded samples are as accurate as properly loaded ones).

Theoretically, the process of counting randomly (Poisson) distributed fibers on a filter surface will give an S_r that depends on the number, N, of fibers counted:

$$S_r = 1/(N)^{1/2} \qquad (1)$$

Thus S_r is 0.1 for 100 fibers and 0.32 for 10 fibers counted. The actual S_r found in a number of studies is greater than these theoretical numbers [17,19,20,21].

An additional component of variability comes primarily from subjective interlaboratory differences. In a study of ten counters in a continuing sample exchange program, Ogden [15] found this subjective component of intralaboratory S_r to be approximately 0.2 and estimated the overall S_r by the term:

$$\frac{[N + (0.2 \cdot N)^2]^{1/2}}{N} \qquad (2)$$

Ogden found that the 90% confidence interval of the individual intralaboratory counts in relation to the means were +2 S_r and - 1.5 S_r. In this program, one sample out of ten was a quality control sample. For laboratories not engaged in an intensive quality assurance program, the subjective component of variability can be higher.

In a study of field sample results in 46 laboratories, the Asbestos Information Association also found that the variability had both a constant component and one that depended on the fiber count [14]. These results gave a subjective interlaboratory component of S_r (on the same basis as Ogden's) for field samples of ca. 0.45. A similar value was obtained for 12 laboratories analyzing a set of 24 field samples [21]. This value falls slightly above the range of S_r (0.25 to 0.42 for 1984-85) found for 80 reference laboratories in the NIOSH PAT program for laboratory-generated samples [17].

A number of factors influence S_r for a given laboratory, such as that laboratory's actual counting performance and the type of samples being analyzed. In the absence of other information, such as from an interlaboratory quality assurance program using field samples, the value for the subjective component of variability is chosen as 0.45. It is hoped that the laboratories will carry out the recommended interlaboratory quality assurance programs to improve their performance and thus reduce the S_r.

The above relative standard deviations apply when the population mean has been determined. It is more useful, however, for laboratories to estimate the 90% confidence interval on the mean count from a single sample fiber count (Figure 1). These curves assume similar shapes of the count distribution for interlaboratory and intralaboratory results [16].

For example, if a sample yields a count of 24 fibers, Figure 1 indicates that the mean interlaboratory count will fall within the range of 227% above and 52% below that value 90% of the time. We can apply these percentages directly to the air concentrations as well. If, for instance, this sample (24 fibers counted) represented a 500-L volume, then the measured concentration is 0.02 fibers/mL (assuming 100 fields counted, 25-mm filter, 0.00785 mm^2 counting field area). If this same sample were counted by a group of laboratories, there is a 90% probability that the mean would fall between 0.01 and 0.08 fiber/mL. These limits should be reported in any comparison of results between laboratories.

Note that the S_r of 0.45 used to derive Figure 1 is used as an estimate for a random group of laboratories. If several laboratories belonging to a quality assurance group can show that their interlaboratory S_r is smaller, then it is more correct to use that smaller S_r. However, the estimated S_r of 0.45 is to be used in the absence of such information. Note also that it has been found that S_r can be higher for certain types of samples, such as asbestos cement [9].

Quite often the estimated airborne concentration from an asbestos analysis is used to compare to a regulatory standard. For instance, if one is trying to show compliance with an 0.5 fiber/mL standard using a single sample on which 100 fibers have been counted, then Figure 1 indicates that the 0.5 fiber/mL standard must be 213% higher than the measured air concentration. This indicates that if one measures a fiber concentration of 0.16 fiber/mL (100 fibers counted), then the mean fiber count by a group of laboratories (of which the compliance laboratory might be one) has a 95% chance of being less than 0.5 fibers/mL; i.e., 0.16 + 2.13 x 0.16 = 0.5.

It can be seen from Figure 1 that the Poisson component of the variability is not very important unless the number of fibers counted is small. Therefore, a further approximation is to simply use +213% and -49% as the upper and lower confidence values of the mean for a 100-fiber count.

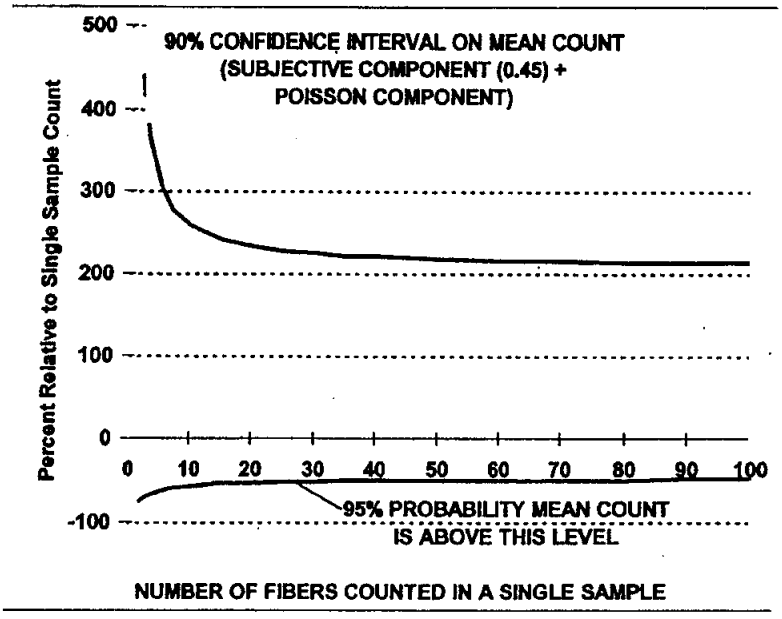

Figure 1. Interlaboratory Precision of Fiber Counts

The curves in Figures 1 are defined by the following equations:

$$UCL = \frac{2X + 2.25 + [(2.25 + 2X)^2 - 4(1 - 2.25 S_r^2) X^2]^{1/2}}{2(1 - 2.25 S_r^2)} \quad (3)$$

$$LCL = \frac{2X + 4 - [(4 + 2X)^2 - 4(1 - 4 S_r^2) X^2]^{1/2}}{2(1 - 4 S_r^2)} \quad (4)$$

where S_r = subjective interlaboratory relative standard deviation, which is close to the total interlaboratory S_r when approximately 100 fibers are counted.
X = total fibers counted on sample
LCL = lower 95% confidence limit.
UCL = upper 95% confidence limit.
Note that the range between these two limits represents 90% of the total range.

REFERENCES:

[1] Leidel, N. A., S. G. Bayer, R. D. Zumwalde, and K. A. Busch. USPHS/NIOSH Membrane Filter Method for Evaluating Airborne Asbestos Fibers, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 79-127 (1979).

[2] Baron, P. A. and G. C. Pickford. "An Asbestos Sample Filter Clearing Procedure," Appl. Ind. Hyg., 1:169-171, 199 (1986).

[3] Occupational Safety and Health Administration, U.S. Department of Labor, Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite Asbestos; Final Rules, 29 CFR Part 1910.1001 Amended June 20, 1986.

[4] Rooker, S. J., N. P. Vaughn, and J. M. LeGuen. "On the Visibility of Fibers by Phase Contrast Microscopy," Amer. Ind. Hyg. Assoc. J., 43, 505-515 (1982).

[5] Baron, P. and G. Deye, "Electrostatic Effects in Asbestos Sampling," Parts I and II Amer. Ind. Hyg. Assoc. J., 51, 51-69 (1990).

[6] Johnston, A. M., A. D. Jones, and J. H. Vincent. "The Influence of External Aerodynamic Factors on the Measurement of the Airborne Concentration of Asbestos Fibers by the Membrane Filter Method," Ann. Occup. Hyg., 25, 309-316 (1982).

[7] Beckett, S.T., "The Effects of Sampling Practice on the Measured Concentration of Airborne Asbestos," Ann. Occup. Hyg., 21, 259-272 (1980).

[8] Jankovic, J. T., W. Jones, and J. Clere. "Field Techniques for Clearing Cellulose Ester Filters Used in Asbestos Sampling," Appl. Ind. Hyg., 1, 145-147 (1986).

[9] Crawford, N. P., H. L. Thorpe, and W. Alexander. "A Comparison of the Effects of Different Counting Rules and Aspect Ratios on the Level and Reproducibility of Asbestos Fiber Counts," Part I: Effects on Level (Report No. TM/82/23), Part II: Effects on Reproducibility (Report No. TM/82/24), Institute of Occupational Medicine, Edinburgh, Scotland (December, 1982).

[10] NIOSH Manual of Analytical Methods, 2nd ed., Vol. 1., P&CAM 239, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-157-A (1977).

[11] Revised Recommended Asbestos Standard, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-169 (1976); as amended in NIOSH statement at OSHA Public Hearing, June 21, 1984.

[12] Asbestos International Association, AIA Health and Safety Recommended Technical Method #1 (RTMI). "Airborne Asbestos Fiber Concentrations at Workplaces by Light Microscopy" (Membrane Filter Method), London (1979).

[13] Abell, M., S. Shulman and P. Baron. The Quality of Fiber Count Data, Appl. Ind. Hyg., 4, 273-285

(1989).
[14] "A Study of the Empirical Precision of Airborne Asbestos Concentration Measurements in the Workplace by the Membrane Filter Method," Asbestos Information Association, Air Monitoring Committee Report, Arlington, VA (June, 1983).
[15] McCrone, W., L. McCrone and J. Delly, "Polarized Light Microscopy," Ann Arbor Science (1978).
[16] Ogden, T. L. "The Reproducibility of Fiber Counts," Health and Safety Executive Research Paper 18 (1982).
[17] Schlecht, P. C. and S. A. Schulman. "Performance of Asbestos Fiber Counting Laboratories in the NIOSH Proficiency Analytical Testing (PAT) Program," Am. Ind. Hyg. Assoc. J., 47, 259-266 (1986).
[18] Chatfield, E. J. Measurement of Asbestos Fiber Concentrations in Workplace Atmospheres, Royal Commission on Matters of Health and Safety Arising from the Use of Asbestos in Ontario, Study No. 9, 180 Dundas Street West, 22nd Floor, Toronto, Ontario, CANADA M5G 1Z8.
[19] Walton, W. H. "The Nature, Hazards, and Assessment of Occupational Exposure to Airborne Asbestos Dust: A Review," Ann. Occup. Hyg., 25, 115-247 (1982).
[20] Cherrie, J., A.D. Jones, and A.M. Johnston. "The Influence of Fiber Density on the Assessment of Fiber Concentration Using the membrane filter Method." Am. Ind. Hyg. Assoc. J., 47(8), 465-74 (1986).
[21] Baron, P. A. and S. Shulman. "Evaluation of the Magiscan Image Analyzer for Asbestos Fiber Counting." Am. Ind. Hyg. Assoc. J., (in press).
[22] Taylor, D. G., P. A. Baron, S. A. Shulman and J. W. Carter. "Identification and Counting of Asbestos Fibers," Am. Ind. Hyg. Assoc. J. 45(2), 84-88 (1984).
[23] "Potential Health Hazards of Video Display Terminals," NIOSH Research Report, June 1981.
[24] "Reference Methods for Measuring Airborne Man-Made Mineral Fibers (MMMF)," WHO/EURO Technical Committee for Monitoring an Evaluating Airborne MMMF, World Health Organization, Copenhagen (1985).
[25] Criteria for a Recommended Standard...Occupational Exposure to Fibrous Glass, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-152 (1977).

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APPENDIX A: CALIBRATION OF THE WALTON-BECKETT GRATICULE:

Before ordering the Walton-Beckett graticule, the following calibration must be done to obtain a counting area (D) 100 µm in diameter at the image plane. The diameter, d_c (mm), of the circular counting area and the disc diameter must be specified when ordering the graticule.

1. Insert any available graticule into the eyepiece and focus so that the graticule lines are sharp and clear.
2. Set the appropriate interpupillary distance and, if applicable, reset the binocular head adjustment so that the magnification remains constant.
3. Install the 40 to 45X phase objective.
4. Place a stage micrometer on the microscope object stage and focus the microscope on the graduated lines.
5. Measure the magnified grid length of the graticule, L_o (µm), using the stage micrometer.
6. Remove the graticule from the microscope and measure its actual grid length, L_a (mm). This can best be accomplished by using a stage fitted with verniers.
7. Calculate the circle diameter, d_c (mm), for the Walton-Beckett graticule:

$$d_c = \frac{L_a}{L_o} \times D. \qquad (5)$$

Example: If L_o = 112 µm, L_a = 4.5 mm and D = 100 µm, then d_c = 4.02 mm.

8. Check the field diameter, D (acceptable range 100 µm ± 2 µm) with a stage micrometer upon receipt of the graticule from the manufacturer. Determine field area (acceptable range 0.00754 mm^2 to 0.00817 mm^2).

APPENDIX B: COMPARISON OF COUNTING RULES:

Figure 2 shows a Walton-Beckett graticule as seen through the microscope. The rules will be discussed as they apply to the labeled objects in the figure.

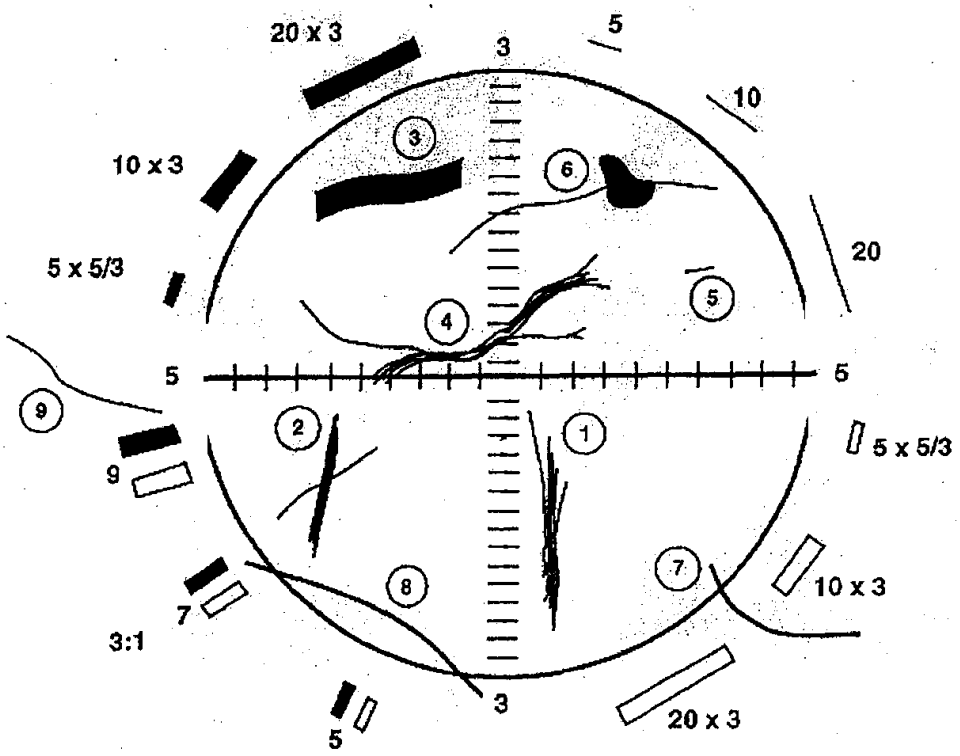

Figure 2. Walton-Beckett graticule with fibers.

These rules are sometimes referred to as the "A" rules.

FIBER COUNT

Object	Count	DISCUSSION
1	1 fiber	Optically observable asbestos fibers are actually bundles of fine fibrils. If the fibrils seem to be from the same bundle the object is counted as a single fiber. Note, however, that all objects meeting length and aspect ratio criteria are counted whether or not they appear to be asbestos.
2	2 fiber	If fibers meeting the length and aspect ratio criteria (length >5 µm and length-to-width ratio >3 to 1) overlap, but do not seem to be part of the same bundle, they are counted as separate fibers.
3	1 fiber	Although the object has a relatively large diameter (>3 µm), it is counted as fiber under the rules. There is no upper limit on the fiber diameter in the counting rules. Note that fiber width is measured at the widest compact section of the object.
4	1 fiber	Although long fine fibrils may extend from the body of a fiber, these fibrils are considered part of the fiber if they seem to have originally been part of the bundle.
5	Do not count	If the object is ≤5 µm long, it is not counted.
6	1 fiber	A fiber partially obscured by a particle is counted as one fiber. If the fiber ends emanating from a particle do not seem to be from the same fiber and each end meets the length and aspect ratio criteria, they are counted as separate fibers.
7	1/2 fiber	A fiber which crosses into the graticule area one time is counted as 1/2 fiber.
8	Do not count	Ignore fibers that cross the graticulate boundary more than once. count
9	Do not count	Ignore fibers that lie outside the graticule boundary.

APPENDIX C. ALTERNATE COUNTING RULES FOR NON-ASBESTOS FIBERS

Other counting rules may be more appropriate for measurement of specific non-asbestos fiber types, such as fibrous glass. These include the "B" rules given below (from NIOSH Method 7400, Revision #2, dated 8/15/87), the World Health Organization reference method for man-made mineral fiber [24], and the NIOSH fibrous glass criteria document method [25]. The upper diameter limit in these methods prevents measurements of non-thoracic fibers. It is important to note that the aspect ratio limits included in these methods vary. NIOSH recommends the use of the 3:1 aspect ratio in counting fibers.

It is emphasized that hybridization of different sets of counting rules is not permitted. Report specifically which set of counting rules are used with the analytical results.

"B" COUNTING RULES:

1. Count only ends of fibers. Each fiber must be longer than 5 µm and less than 3 µm diameter.
2. Count only ends of fibers with a length-to-width ratio equal to or greater than 5:1.
3. Count each fiber end which falls within the graticule area as one end, provided that the fiber meets rules 1 and 2 above. Add split ends to the count as appropriate if the split fiber segment also meets the criteria of rules 1 and 2 above.
4. Count visibly free ends which meet rules 1 and 2 above when the fiber appears to be attached to another particle, regardless of the size of the other particle. Count the end of a fiber obscured by another particle if the particle covering the fiber end is less than 3 µm in diameter.
5. Count free ends of fibers emanating from large clumps and bundles up to a maximum of 10 ends (5 fibers), provided that each segment meets rules 1 and 2 above.
6. Count enough graticule fields to yield 200 ends. Count a minimum of 20 graticule fields. Stop at 100 graticule fields, regardless of count.
7. Divide total end count by 2 to yield fiber count.

APPENDIX D. EQUIVALENT LIMITS OF DETECTION AND QUANTITATION

	fiber density on filter*		fiber concentration in air, f/cc	
	fibers per 100 fields	fibers/mm²	400-L air sample	1000-L air sample
	200	255	0.25	0.10
	100	127	0.125	0.05
LOQ	80	102	0.10	0.04
	50	64	0.0625	0.025
	25	32	0.03	0.0125
	20	25	0.025	0.010
	10	12.7	0.0125	0.005
	8	10.2	0.010	0.004
LOD	5.5	7	0.00675	0.0027

* Assumes 385 mm² effective filter collection area, and field area = 0.00785 mm², for relatively "clean" (little particulate aside from fibers) filters.

ASBESTOS by TEM 7402

FORMULA: Various MW: Various CAS: Various RTECS: Various

METHOD: 7402 **EVALUATION: PARTIAL** **Issue 1: 15 May 1989**
Issue 2: 15 August 1994

OSHA : 0.1 asbestos fibers (>5 µm long)/cc; 1 f/cc/30 min excursion; carcinogen
MSHA: 2 asbestos fibers/cc
NIOSH: 0.1 f/cc (fibers > 5 µm long)/400 L; carcinogen
ACGIH: 0.2 crocidolite; 0.5 amosite; 2 chrysotile and other asbestos, fibers/cc; carcinogen

PROPERTIES: solid, fibrous, crystalline, anistropic

SYNONYMS [CAS#]: actinolite [77536-66-4] or ferroactinolite [15669-07-5]; amosite [12172-73-5]; anthophyllite [77536-67-5]; chrysotile [12001-29-5]; serpentine [18786-24-8]; crocidolite [12001-28-4]; tremolite [77536-68-6]; amphibole asbestos [1332-21-4].

SAMPLING

SAMPLER: FILTER (0.45- to 1.2-µm cellulose ester membrane, 25-mm diameter; conductive cassette)

FLOW RATE: 0.5 to 16 L/min

VOL-MIN*: 400 L @ 0.1 fiber/cc
-MAX*: (step 4, sampling)
*Adjust for 100 to 1300 fibers/mm^2

SHIPMENT: routine (pack to reduce shock)

SAMPLE STABILITY: stable

BLANKS: 2 to 10 field blanks per set

ACCURACY

RANGE STUDIED: 80 to 100 fibers counted

BIAS: not determined

OVERALL PRECISION ($\hat{S}_{rT}$): see EVALUATION OF METHOD

ACCURACY: not determined

MEASUREMENT

TECHNIQUE: MICROSCOPY, TRANSMISSION ELECTRON (TEM)

ANALYTE: asbestos fibers

SAMPLE PREPARATION: modified Jaffe wick

EQUIPMENT: transmission electron microscope; energy dispersive X-ray system (EDX) analyzer

CALIBRATION: qualitative electron diffraction; calibration of TEM magnification and EDX system

RANGE: 100 to 1300 fibers/mm^2 filter area [1]

ESTIMATED LOD: 1 confirmed asbestos fiber above 95% of expected mean blank value

PRECISION ($\hat{S}_r$): 0.28 when 65% of fibers are asbestos; 0.20 when adjusted fiber count is applied to PCM count [2].

APPLICABILITY: The quantitative working range is 0.04 to 0.5 fiber/cc for a 1000-L air sample. The LOD depends on sample volume and quantity of interfering dust, and is <0.01 fiber/cc for atmospheres free of interferences. This method is use d to determine asbestos fibers in the optically visible range and is intended to complement the results obtained by phase con trast microscopy (Method 7400).

INTERFERENCES: Other amphibole particles that have aspect ratios greater than 3:1 and elemental compositions similar to the asbestos minerals may interfere in the TEM analysis. Some non-amphibole minerals may give electron diffraction patterns similar to amphiboles. High concentrations of background dust interfere with fiber identification. Some non-asbestos amphibole m inerals may give electron diffraction patterns similar to asbestos amphiboles.

OTHER METHODS: This method is designed for use with Method 7400 (phase contrast microscopy).

REAGENTS:

1. Acetone. (See SPECIAL PRECAUTIONS.)

EQUIPMENT:

1. Sampler: field monitor, 25-mm, three-piece cassette with ca. 50-mm electrically-conductive extension cowl, cellulose ester membrane filter, 0.45- to 1.2-µm pore size, and backup pad.
   NOTE 1: Analyze representative filters for fiber background before use. Discard the filter lot if mean count is >5 fibers/100 fields. These are defined as laboratory blanks.
   NOTE 2: Use an electrically-conductive extension cowl to reduce electrostatic effects on fiber sampling and during sample shipment. Ground the cowl when possible during sampling.
   NOTE 3: 0.8-µm pore size filters are recommended for personal sampling. 0.45-µm filters are recommended for sampling when performing TEM analysis on the samples because the particles deposit closer to the filter surface. However, the higher pressure drop through these filters normally preclude their use with personal sampling pumps.
2. Personal sampling pump, 0.5 to 16 L/min, with flexible connecting tubing.
3. Microscope, transmission electron, operated at ca. 100 kV, with electron diffraction and energy-dispersive X-ray capabilities, and having a fluorescent screen with inscribed or overlaid calibrated scale (Step 15).
   NOTE: The scale is most efficient if it consists of a series of lines inscribed on the screen or partial circles every 2 cm distant from the center.
4. Diffraction grating replica with known number of lines/mm.
5. Slides, glass, pre-cleaned, 25- x 75-mm.
6. Knife, surgical steel, curved-blade.
7. Tweezers.
8. Grids, 200-mesh TEM copper, (optional: carbon-coated).
9. Petri dishes, 15-mm depth. The top and bottom of the petri dish must fit snugly together. To assure a tight fit, grind the top and bottom pieces together with an abrasive such as carborundum to produce a ground-glass contact surface.
10. Foam, clean polyurethane, spongy, 12-mm thick.
11. Filters, Whatman No. 1 qualitative paper or equivalent, or lens paper.
12. Vacuum evaporator.
13. Cork borer, (about 8-mm).
14. Pen, waterproof, marking.
15. Reinforcement, page, gummed.
16. Asbestos standard bulk materials for reference; e.g. SRM #1866, available from the National Institute of Standards and Technology.
17. Carbon rods, sharpened to 1 mm x 8 mm.
18. Microscope, light, phase contrast (PCM), with Walton-Beckett graticule (see method 7400).
19. Grounding wire, 22-gauge, multi-strand.
20. Tape, shrink- or adhesive-.

SPECIAL PRECAUTIONS: Acetone is extremely flammable (flash point = 0 °F). Take precautions not to ignite it. Heating of acetone must be done in a fume hood using a flameless, spark-free heat source. Asbestos is a confirmed human carcinogen. Handle only in a well-ventilated fume hood.

SAMPLING:

1. Calibrate each personal sampling pump with a representative sampler in line.
2. For personal sampling, fasten sampler to worker's lapel near worker's mouth. Remove the top cover from cowl extension ("open-face") and orient sampler face down. Wrap joint between extender and monitor body with tape to help hold the cassette together and provide a marking surface to identify the cassette. Where possible, especially at low %RH, attach sampler to electrical ground to reduce electrostatic effects during sampling.
3. Submit at least two field blanks (or 10% of the total samples, whichever is greater) for each set of samples. Remove top covers from the field blank cassettes and store top covers and cassettes in a clean area (e.g., closed bag or box) during sampling. Replace top covers when sampling is completed.
4. Sample at 0.5 to 16 L/min [3]. Adjust sampling rate, Q (L/min), and time, t (min), to produce fiber density, E, of 100 to 1300 fibers/mm ^{2} [$3.85 \cdot 10^4$ to $5 \cdot 10^5$ fibers per 25-mm filter with effective collection area (A_c = 385 mm^2)] for optimum accuracy. Do not exceed ca. 0.5 mg total dust loading on the filter. These variables are related to the action level (one-half the current standard), L (fibers/cc), of the fibrous aerosol being sampled by:

$$t = \frac{A_c \cdot E}{Q \cdot L \cdot 10^3}, \text{ min.}$$

   NOTE: The purpose of adjusting sampling times is to obtain optimum fiber loading on the filter. A sampling rate of 1 to 4 L/min for 8 h (700 to 2800 L) is appropriate in atmospheres containing ca. 0.1 fiber/cc in the absence of significant amounts of non-asbestos dust. Dusty atmospheres require smaller sample volumes (≤400 L) to obtain countable samples. In such cases take short, consecutive samples and average the results over the total collection time. For documenting episodic exposures, use high rates (7 to 16 L/min) over shorter sampling times. In relatively clean atmospheres, where targeted fiber concentrations are much less than 0.1 fiber/cc, use larger sample volumes (3000 to 10000 L) to achieve quantifiable loadings. Take care, however, not to overload the filter with background dust [3].
5. At the end of sampling, replace top cover and small end caps.
6. Ship samples upright with conductive cowl attached in a rigid container with packing material to prevent jostling or damage.
   NOTE: Do not use untreated polystyrene foam in the shipping container because electrostatic forces may cause fiber loss from sample filter.

SAMPLE PREPARATION:

7. Remove circular sections from any of three quadrants of each sample and blank filter using a cork borer [4]. The use of three grid preparations reduces the effect of local variations in dust deposit on the filter.
8. Affix the circular filter sections to a clean glass slide with a gummed page reinforcement. Label the slide with a waterproof marking pen.
   NOTE: Up to eight filter sections may be attached to the same slide.
9. Place the slide in a petri dish which contains several paper filters soaked with 2 to 3 mL acetone. Cover the dish. Wait 2 to 4 min for the sample filter(s) to fuse and clear.
   NOTE: The "hot block" clearing technique [5] of Method 7400 or the DMF clearing technique [6] may be used instead of steps 8 and 9.
10. Transfer the slide to a rotating stage inside the bell jar of a vacuum evaporator. Evaporate a 1-by 5-mm section of a graphite rod onto the cleared filter(s). Remove the slide to a clean, dry, covered petri dish [4].
11. Prepare a second petri dish as a Jaffe wick washer with the wicking substrate prepared from filter or lens paper placed on top of a 12-mm thick disk of clean, spongy polyurethane foam [7].

Cut a V-notch on the edge of the foam and filter paper. Use the V-notch as a reservoir for adding solvent.

NOTE: The wicking substrate should be thin enough to fit into the petri dish without touching the lid.

12. Place the TEM grid on the filter or lens paper. Label the grids by marking with a pencil on the filter paper or by putting registration marks on the petri dish halves and marking with a waterproof marker on the dish lid. In a fume hood, fill the dish with acetone until the wicking substrate is saturated.

NOTE: The level of acetone should be just high enough to saturate the filter paper without creating puddles.

13. Remove about a quarter section of the carbon-coated filter from the glass slide using a surgical knife and tweezers. Carefully place the excised filter, carbon side down, on the appropriately-labeled grid in the acetone-saturated petri dish. When all filter sections have been transferred, slowly add more solvent to the wedge-shaped trough to raise the acetone level as high as possible without disturbing the sample preparations. Cover the petri dish. Elevate one side of the petri dish by placing a slide under it (allowing drops of condensed acetone to form near the edge rather than in the center where they would drip onto the grid preparation).

CALIBRATION AND QUALITY CONTROL:

14. Determine the TEM magnification on the fluorescent screen:
    a. Define a field of view on the fluorescent screen either by markings or physical boundaries.
    NOTE: The field of view must be measurable or previously inscribed with a scale or concentric circles (all scales should be metric) [7].
    b. Insert a diffraction grating replica into the specimen holder and place into the microscope. Orient the replica so that the grating lines fall perpendicular to the scale on the TEM fluorescent screen. Ensure that goniometer stage tilt is zero.
    c. Adjust microscope magnification to 10,000X. Measure the distance (mm) between the same relative positions (e.g., between left edges) of two widely-separated lines on the grating replica. Count the number of spaces between the lines.
    NOTE: On most microscopes the magnification is substantially constant only within the central 8- to 10-cm diameter region of the fluorescent screen.
    d. Calculate the true magnification (M) on the fluorescent screen:

$$m = \frac{X \cdot G}{Y}$$

where: X = total distance (mm) between the two grating lines;
G = calibration constant of the grating replica (lines/mm);
Y = number of grating replica spaces counted

    e. After calibration, note the apparent sizes of 0.25 and 5.0 µm on the fluorescent screen. (These dimensions are the boundary limits for counting asbestos fibers by phase contrast microscopy.)

15. Measure 20 grid openings at random on a 200-mesh copper grid by placing a grid on a glass slide and examining it under the PCM. Use the Walton-Beckett graticule to measure the grid opening dimensions. Calculate an average graticule field dimension from the data and use this number to calculate the graticule field area for an average grid opening.

NOTE: A grid opening is considered as one graticule field.

16. Obtain reference selected area electron diffraction (SAED) or microdiffraction patterns from standard asbestos materials prepared for TEM analysis.

NOTE: This is a visual reference technique. No quantitative SAED analysis is required [7]. Microdiffraction may produce clearer patterns on very small fibers or fibers partially obscured by other material.

    a. Set the specimen holder at zero tilt.

b. Center a fiber, focus, and center the smallest field-limiting aperture on the fiber. Obtain a diffraction pattern. Photograph each distinctive pattern and keep the photo for comparison to unknowns.

NOTE: Not all fibers will present diffraction patterns. The objective lens current may need adjustment to give optimum pattern visibility. There are many more amphiboles which give diffraction patterns similar to the analytes named on p. 7402-1. Some, but not all, of these can be eliminated by chemical separations. Also, some non-amphiboles (e.g., pyroxenes, some talc fibers) may interfere.

17. Acquire energy-dispersive X-ray (EDX) spectra on approximately 5 fibers having diameters between 0.25 and 0.5 μm of each asbestos variety obtained from standard reference materials [7].

NOTE: The sample may require tilting to obtain adequate signal. Use same tilt angle for all spectra.

a. Prepare TEM grids of all asbestos varieties.
b. Use acquisition times (at least 100 sec) sufficient to show a silicon peak at least 75% of the monitor screen height at a vertical scale of ≥500 counts per channel.
c. Estimate the elemental peak heights visually as follows:
   (1) Normalize all peaks to silicon (assigned an arbitrary value of 10).
   (2) Visually interpret all other peaks present and assign values relative to the silicon peak.
   (3) Determine an elemental profile for the fiber using the elements Na, Mg, Si, Ca, and Fe. Example: 0-4-10-3-<1 [7].
      NOTE: In fibers other than asbestos, determination of Al, K, Ti, S, P, and F may also be required for fiber characterization.
   (4) Determine a typical range of profiles for each asbestos variety and record the profiles for comparison to unknowns.

MEASUREMENT:

18. Perform a diffraction pattern inspection on all sample fibers counted under the TEM, using the procedures given in step 17. Assign the diffraction pattern to one of the following structures:
   a. chrysotile;
   b. amphibole;
   c. ambiguous;
   d. none.

   NOTE: There are some crystalline substances which exhibit diffraction patterns similar to those of asbestos fibers. Many of these, (brucite, halloysite, etc.) can be eliminated from consideration by chemistry. There are, however, several minerals (e.g., pyroxenes, massive amphiboles, and talc fibers) which are chemically similar to asbestos and can be considered interferences. The presence of these substances may warrant the use of more powerful diffraction pattern analysis before positive identification can be made. If interferences are suspected, morphology can play an important role in making positive identification.

19. Obtain EDX spectra in either the TEM or STEM modes from fibers on field samples using the procedure of step 18. Using the diffraction pattern and EDX spectrum, classify the fiber:
   a. For a chrysotile structure, obtain EDX spectra on the first five fibers and one out of ten thereafter. Label the range profiles from 0-5-10-0-0 to 0-10-10-0-0 as "chrysotile."
   b. For an amphibole structure, obtain EDX spectra on the first 10 fibers and one out of ten thereafter. Label profiles ca. 0-2-10-0-7 as "possible amosite"; profiles ca. 1-1-10-0-6 as "possible crocidolite"; profiles ca. 0-4-10-3-<1 as "possible tremolite"; and profiles ca. 0-3-10-0-1 as "possible anthophyllite."

      NOTE: The range of profiles for the amphiboles will vary up to ± 1 unit for each of the elements present according to the relative detector efficiency of the spectrometer.

   c. For an ambiguous structure, obtain EDX spectra on all fibers. Label profiles similar to the chrysotile profile as "possible chrysotile." Label profiles similar to the various amphiboles as "possible amphiboles." Label all others as "unknown" or "non-asbestos."

20. Counting and Sizing:
    a. Insert the sample grid into the specimen grid holder and scan the grid at zero tilt at low magnification (ca. 300 to 500X). Ensure that the carbon film is intact and unbroken over ca. 75% of the grid openings.
    b. In order to determine how the grids should be sampled, estimate the number of fibers per grid opening during a low-magnification scan (500 to 1000X). This will allow the analyst to cover most of the area of the grids during the fiber count and analysis. Use the following rules when picking grid openings to count [7,8]:
        (1) Light loading (<5 fibers per grid opening): count total of 40 grid openings.
        (2) Moderate loading (5 to 25 fibers per grid opening): count minimum of 40 grid openings or 100 fibers.
        (3) Heavy loading (>25 fibers per opening): count a minimum of 100 fibers and at least 6 grid openings.

        Note that these grid openings should be selected approximately equally among the three grid preparations and as randomly as possible from each grid.
    c. Count only grid openings that have the carbon film intact. At 500 to 1000X magnification, begin counting at one end of the grid and systematically traverse the grid by rows, reversing direction at row ends. Select the number of fields per traverse based on the loading indicated in the initial scan. Count at least 2 field blanks per sample set to document possible contamination of the samples. Count fibers using the following rules:
        (1) Count all particles with diameter greater than 0.25 µm that meet the definition of a fiber (aspect ratio ≥3:1, longer than 5 µm). Use the guideline of counting all fibers that would have been counted under phase contrast light microscopy (Method 7400). Use higher magnification (10000X) to determine fiber dimensions and countability under the acceptance criteria. Analyze a minimum of 10% of the fibers, and at least 3 asbestos fibers, by EDX and SAED to confirm the presence of asbestos. Fibers of similar morphology under high magnification can be identified as asbestos without SAED. Particles which are of questionable morphology should be analyzed by SAED and EDX to aid in identification.
        (2) Count fibers which are partially obscured by the grid as half fibers.
            NOTE: If a fiber is partially obscured by the grid bar at the edge of the field of view, count it as a half fiber only if more than 2.5 µm of fiber is visible.
        (3) Size each fiber as it is counted and record the diameter and length:
            (a) Move the fiber to the center of the screen. Read the length of the fiber directly from the scale on the screen.
                NOTE 1: Data can be recorded directly off the screen in µm and later converted to µm by computer.
                NOTE 2: For fibers which extend beyond the field of view, the fiber must be moved and superimposed upon the scale until its entire length has been measured.
            (b) When a fiber has been sized, return to the lower magnification and continue the traverse of the grid area to the next fiber.
    d. Record the following fiber counts:
        (1) f_s, f_b = number of asbestos fibers in the grid openings analyzed on the sample filter and corresponding field blank, respectively.
        (2) F_s, F_b = number of fibers, regardless of identification, in the grid openings analyzed on the sample filter and corresponding field blank, respectively.

CALCULATIONS:

21. Calculate and report the fraction of optically visible asbestos fibers on the filter, $(f_s - f_b)/(F_s - F_b)$. Apply this fraction to fiber counts obtained by PCM on the same filter or on other filters for which the TEM sample is representative. The final result is an asbestos fiber count. The type of asbestos present should also be reported.
22. As an integral part of the report, give the model and manufacturer of the TEM as well as the model and manufacturer of the EDX system.

EVALUATION OF METHOD:

The TEM method, using the direct count of asbestos fibers, has been shown to have a precision of 0.275 (s_r) in an evaluation of mixed amosite and wollastonite fibers. The estimate of the asbestos fraction, however, had a precision of 0.11 (s_r). When this fraction was applied to the PCM count, the overall precision of the combined analysis was 0.20 [2].

REFERENCES:

[1] Walton, W. H. "The Nature, Hazards, and Assessment of Occupational Exposure to Airborne Asbestos Dust: A Review," Ann. Occup. Hyg., 25, 115-247 (1982).
[2] Taylor, D. G., P. A. Baron, S. A. Shulman and J. W. Carter. "Identification and Counting of Asbestos Fibers," Am. Ind. Hyg. Assoc. J. 45(2), 84-88 (1984).
[3] Johnston, A. M., A. D. Jones, and J. H. Vincent. "The Influence of External Aerodynamic Factors on the Measurement of the Airborne Concentration of Asbestos Fibers by the Membrane Filter Method," Ann. Occup. Hyg., 25, 309-316 (1982).
[4] Zumwalde, R. D. and J. M. Dement. Review and Evaluation of Analytical Methods for Environmental Studies of Fibrous Particulate Exposures, NIOSH Technical Information Bulletin #77-204 (1977).
[5] Baron, P. A. and G. C. Pickford. "An Asbestos Sample Filter Clearing Procedure," Appl. Ind. Hyg., 1:169-171,199 (1986).
[6] LeGuen, J. M. and S. Galvin "Clearing and Mounting Techniques for the Evaluation of Asbestos Fibers by the Membrane Filter Method" Ann. Occup. Hyg. 24, 273-280 (1981).
[7] Yamate, G., S. A. Agarwal, and R. D. Gibbons. "Methodology for the Measurement of Airborne Asbestos by Electron Microscopy," EPA Contract No. 68-02-3266 (in press).
[8] Steel, E. B. and J. A. Small. "Accuracy of Transmission Electron Microcopy for the Analysis of Asbestos in Ambient Environments," Anal. Chem., 57, 209-213 (1985).

METHOD REVISED BY:

Paul A. Baron, Ph.D.; NIOSH/DPSE.

Attachment 4

Eric Chatfield, Ph.D.

"Very few commercial TEM labs are competent to perform valid analysis of the complicated mineralogical mixtures that you find in mining and quarrying operations."

"The accreditation of a TEM or a PLM lab is unrelated to the ability of the TEM or PLM lab to perform analyses of these complex mixtures such as those that exist in mines or quarries."

"The fundamental problem is the individual – it isn't a question of the individual lab; it's a question of the individual analyst, and the level of training and knowledge that exists in the individual analyst. And, unfortunately, that training is simply not there."

"Moving on the PCM methods"

"Using the current PCM fiber counting criteria, cleavage fragments are reported as fibers, even when there 's no asbestos present at all."

Ann Wylie, Ph.D.

"And I think it's very important, when you think about these regulations, to keep in mind that the longer than five and the 3:1 are not definitions. They never have been definitions. They were counting criteria. That's all they ever were. And that's all they ever are today. They are not definitions for asbestos."

"it's inclusive of asbestos, but not specific for it."

"Cleavage fragments get wider as they get longer. And that's a characteristic of them. Whereas for asbestos, width is essentially independent of length. That's because of the nature of the way asbestos forms. It forms as unit fibrils."

"Actually, when you look at airborne particles in bulk populations you see the same characteristics. It's not as though you have something totally different airborne than you would have in bulk."

"The bulk populations of asbestos have distinctive characteristics that easily enable you to tell whether they're asbestos or not. This is an easy thing to do."

"But one thing that you really need to be aware of is that all these methods were designed for the asbestos-containing materials – not the mining environment – and that no method is adequate to measure quantitatively amounts of asbestos in low abundance. And all methods need attention to the literature, and a well-trained mineralogist familiar with the mining environment to apply them correctly."

Richard Lee, Ph.D.

"As the PEL is lowered, these factors, these interferences from cellulose fibers, other minerals, from cleavage fragments, become more important."

"Sometimes you can't tell on a single simple fiber. This is why Dr. Wylie mentioned you have to do populations."

"A whole set of issues have developed because of the application of historical definitions into the electron microscope, and the use of the terminology, and the aspect ratios and sizes created a set of problems that persist today. They're responsible for the errors and mistakes that have caused various companies and individuals substantial money, shut down organizations like Reserve because of these definitional issues. They will surely pop up more frequently with any reduction of the PEL to a point where the dose you're trying to measure is not substantially different than the background concentration of the interference."

Mac Ross, Ph.D.

"The crushing of any rock produces some mineral particles that may be within the size range of specified federal regulations. If correct, definitions of the truly hazardous material; that is, asbestos, are not made, it presents a formidable problem to those analyzing for the asbestos minerals in the multitude of different mineral particles that may be found in rock dusts, - - "

"Many different types of non-fibrous amphiboles are found in many types of common rocks. And many of these amphiboles might be considered asbestos, depending on the professional training of the analyst, on the equipment used for analysis."

ATTACHMENT 5

THE ASBESTIFORM AND NONASBESTIFORM MINERAL GROWTH HABIT AND THEIR RELATIONSHIP TO CANCER STUDIES

A PICTORIAL PRESENTATION

The Asbestiform and Nonasbestiform Mineral Growth Habit and Their Relationship to Cancer Studies

Kelly F. Bailey, CIH
Manager, Occupational Health
Vulcan Materials Company
Birmingham, Alabama

John Kelse
Corporate Industrial Hygienist
Manager, Risk Management Dept.
R. T. Vanderbilt Company
Norwalk, Connecticut

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President
R. J. Lee Group, Inc.
Monroeville, Pennsylvania

The recognition and regulation of asbestiform and nonasbestiform minerals is of critical concern to the entire mining and aggregates industry, to individuals exposed to these materials and to the economic vitality of the United States.

CONTENTS

INTRODUCTION

It has long been recognized that the inhalation of excessive asbestos fibers, over time, is associated with significant pulmonary disease in humans. The link between asbestos, lung cancer and malignant mesothelioma is well established. Asbestos is perhaps the most feared mineral risk and certainly is among the most publicized, litigated and studied.

Despite this attention, a clear understanding of what asbestos actually is remains a source of confusion to many. This is often demonstrated when commercial asbestos is not known "a priori" to exist in a dust exposure. Nowhere is this problem better demonstrated than the decades old confusion over the difference between asbestiform and nonasbestiform crystal growth.

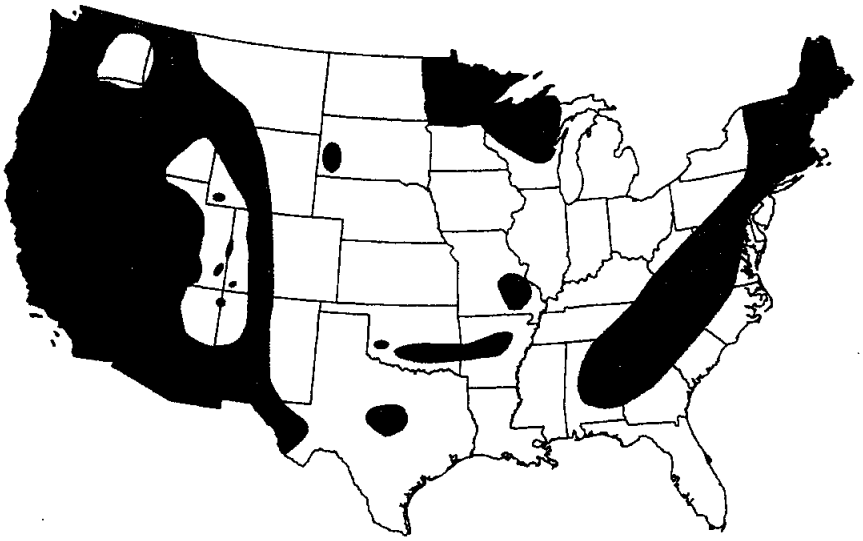
No federal regulatory agency treats elongated nonasbestiform mineral particulates as asbestos, yet some in the regulatory and health community believe that they should. These individuals mistakenly believe that the essential difference between nonasbestiform minerals and asbestos is not significant from both a mineralogic and biologic perspective.

This pictorial presentation demonstrates that important mineralogic and health differences do, in fact, exist. Health researchers who fail to understand these differences can and have attributed the carcinogenic effects of asbestos exposure to nonasbestiform minerals. Because these common, nonasbestiform rock-forming minerals make up so much of the earth's crust, it is important that this error be avoided.

WHY IS THIS DISTINCTION IMPORTANT?

The nonasbestiform minerals are common hard rock forming minerals found throughout the earth's crust. Unlike asbestos, they are not at all rare.

The map below shows the general areas in the continental United States where igneous and metamorphic rocks are likely to be found on or near the surface. Amphiboles and serpentine, the two mineral groups that contain mineral species that may form asbestos, are restricted in their occurrence to these types of rock. When amphiboles and serpentine form part of the bedrock, they may also be found in the overlying soil. All the rock and soil in the shaded areas, however, do not contain amphibole and serpentine, and the occurrence of the asbestiform habits of these minerals in the shaded areas is even more restricted. The shaded areas do not mean that every rock or soil mass in that area contains these minerals, but it does mean that they are often present in these areas.



igneous or metamorphic rocks (1)

The composition of the rock also affects the likelihood of finding asbestos. Asbestos is more likely to form during the metamorphism of limestone, mafic and ultramafic rocks and alkali igneous rocks than during the metamorphism of other common rocks such as granite and sandstone. Furthermore, many of the amphiboles, particularly those that contain a significant amount of aluminum, never form asbestiform fibers. Therefore, while the nonasbestiform habits of amphibole and serpentine are common throughout the shaded areas, asbestos occurrences are localized and uncommon.

The U.S. Bureau of Mines reports that the regulation of nonasbestiform minerals as asbestos would significantly impact the mining of important mineral commodities such as gold, copper, iron, crushed stone, sand, gravel and talc. Downstream users of these mineral commodities such as construction, refractories, smelters, ceramics and paint manufacturers, would be affected as well (2).

Therefore, it is important that these nonasbestiform minerals be properly assessed with respect to their health risk.

The goal of this document is to clearly and succinctly demonstrate that mineralogical and biological differences exist between asbestos and common nonasbestiform minerals. To accomplish this objective, this presentation:

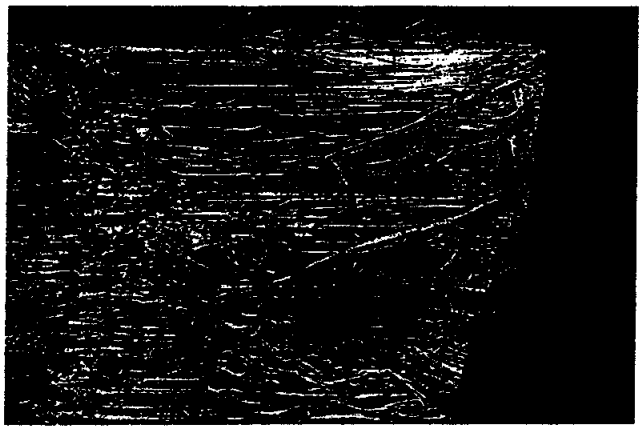
- **DESCRIBES THE MINERALOGICAL DIFFERENCES BETWEEN ASBESTIFORM AND NONASBESTIFORM MINERALS.**

- **CLARIFIES THE MINERAL EXPOSURES CITED IN KEY HEALTH STUDIES.**

- **SUMMARIZES THE OUTCOME OF THIS COMPARISON.**

REFERENCE EXHIBIT 1

What is Asbestos?



In the *Glossary of Geology*, asbestos is defined as. . .

"A commercial term applied to a group of highly fibrous silicate minerals that readily separate into *long, thin, strong* fibers of sufficient flexibility to be woven. . ." (3).

This definition has been further expanded based on mineral-crystallographic studies over the last decade or so:

A. ASBESTOS - A collective mineralogic term that describes a variety of certain silicates belonging to the serpentine and amphibole mineral groups, which have crystallized in the asbestiform habit causing them to be easily separated into long, thin, flexible, strong fibers when crushed or processed. Included in the definition are: chrysotile, crocidolite, asbestiform grunerite (amosite), anthophyllite asbestos, tremolite asbestos and actinolite asbestos. The nomenclature and composition of amphibole minerals should conform with International Mineralogical Association recommendations (Leake, B.E., *Nomenclature of Amphiboles.* American Mineralogist. Vol. 82, 1019 - 1037, 1997).

B. ASBESTOS FIBERS - Asbestiform mineral fiber populations generally have the following characteristics when viewed by light microscopy:

1. Mean aspect ratios ranging from 20:1 to 100:1 or higher for fibers longer than 5 µm,

2. Very thin fibrils, usually less than 0.5 µm in width,

3. Parallel fibers occurring in bundles, and

4. One or more of the following:
   a) Fiber bundles displaying splayed ends,
   b) Matted masses of individual fibers,
   c) Fibers showing curvature

This definition represents the consensus of a group of mineral scientists, several of whom have published extensively in this area (see Appendix I).

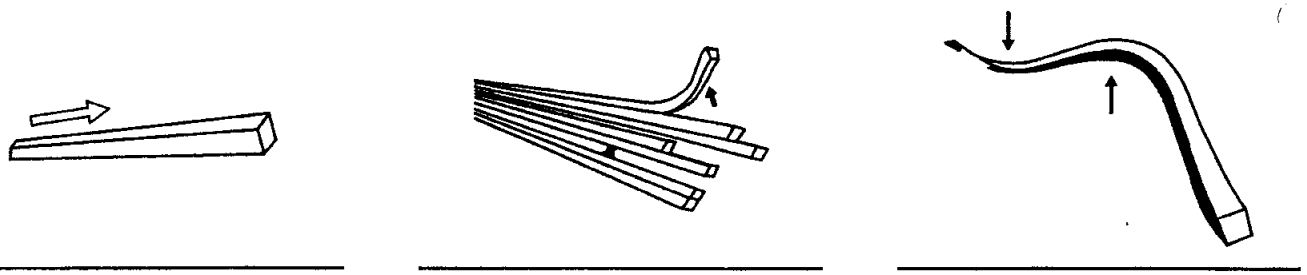
Morphological properties are difficult to apply to single particles when classifying them as a cleavage fragment or a fiber. Distinctions on morphology are most reliably made on populations. Furthermore, in air and water samples, in which particles are often less than 5 μm in length, the presence of asbestos should be verified in bulk material at the source before identification of particles as asbestos can be reliably made. Bulk materials display the full range of distinctive morphological characteristics, but in fibers collected from air and water, the range of morphological properties is more limited.

Asbestiform fibers normally exhibit anomalous optical properties that are distinctive. For example, under polarized light microscopy, asbestiform fibers may display parallel extinction in all orientations, they may display oblique extinction in some orientations at angles that are less than those characteristic of ordinary amphibole fragments in the same crystallographic orientation, they may have only two principal indices of refraction (as opposed to the expected three), or they may display orthorhombic optical properties when monoclinic optical properties are expected. It should be noted also that within asbestos fiber populations that exhibit anomalous properties, there might also be wide single crystals, often referred to as byssollite fibers, whose optical properties are normal or which sometimes exhibit their own distinctive optical abnormality, lack of extinction altogether when oriented on (010).

Asbestos also is characterized by high tensile strength. This property results in difficulty on grinding, for example matting in a mortar and pestle. In contrast, byssollite, the fibrous nonasbestiform habit characterized by brittle, glassy fibers of >1 μm in width and cleavage fragments will easily reduce to a powder under the same circumstances.

Although asbestiform crystal growth is very rare in nature, under the right geologic conditions approximately 100 minerals may be formed in this manner - not just the six minerals we refer to as asbestos (76). Evidence on the carcinogenicity of asbestiform minerals that are not asbestos is mixed, but there is no compelling evidence that all asbestiform minerals are carcinogenic. Different minerals have different biodurabilities, surface chemistries, friabilities in vivo, and bioavailability differences that influence their biological activities (77). Asbestiform richterite, winchite and erionite are examples of fibers that appear to pose a risk similar to that of asbestos (74,78) In contrast, asbestiform talc (72) and minerals such as xonotlite (commonly found in an asbestiform habit but is water soluble) do not appear to pose the same risk.

ASBESTIFORM



In the asbestiform habit, fibers grow almost exclusively in one direction and exhibit narrow width (on the order of 0.1 μm). Fibers that are visible to the eye are bundles of individual crystal fibers known as "fibrils". In some deposits, there is a range in fibril width, sometimes extending up to as much as 0.5 μm. Asbestiform fibers wider than 1.0 μm are always bundles of fibrils. Asbestiform minerals have fibrils that are easily separated although variability exists. In populations of asbestiform fibers, the distribution of particle widths will reflect single fibrils as well as bundles of fibrils. Under the light microscope, this "polyfilamentous" characteristic of fibers is evident, and **is the single most important morphological characteristic of the asbestiform habit**. Asbestiform fibers are flexible and exhibit high tensile strength. The flexibility may be accounted for by the very narrow widths of fibrils and perhaps by the ability of fibrils to slide past one another on bending.

Six minerals have been regulated as asbestos. These are listed below:

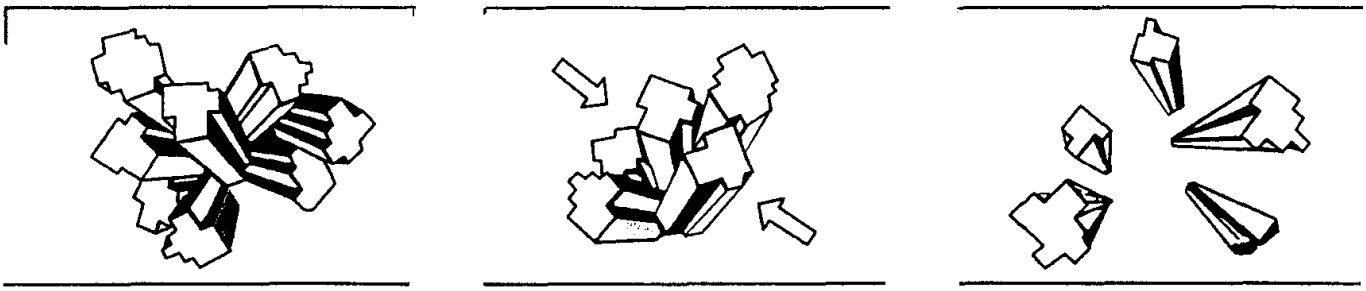
ASBESTIFORM VARIETY (Asbestos, CAS No. 1332-21-4*)	
SERPENTINE GROUP	
chrysotile	(CAS No. 12001-29-5)
AMPHIBOLE GROUP	
crocidolite	(CAS No. 12001-28-4)
grunerite asbestos (amosite)	(CAS No. 12172-73-5*)
anthophyllite asbestos	(CAS No. 77536-67-5*)
tremolite asbestos	(CAS No. 77536-68-6*)
actinolite asbestos	(CAS No. 77536-66-4*)

The presence of an asterisk (*) following a CAS Registry Number indicates that the registration is for a substance which CAS does not treat in its regular CA index processing as a unique chemical entity.

For asbestiform fibers to grow, there must be mineral rich fluids that are either associated with regional metamorphism or contact metamorphism around crystallizing igneous bodies. The vast majority of the occurrences of asbestos are small because, in addition to metamorphic fluids, there must be open spaces into which the fibers can grow, a condition restricted to the upper portions of the earth's crust in structurally specific environments such as faults, joints, the axes of folds, etc. Only rarely are large portions of a rock composed of asbestos.

The most common occurrence of asbestos is in cross-fiber or slip fiber veins. In the former, the fiber axes are perpendicular to the walls of narrow openings in the host rock; in the latter, they are parallel. Asbestos rarely occurs as mass fiber bundles in which fibrillar growth is in many directions. This growth pattern is not clearly related to planar structural features of the rock.

NONASBESTIFORM



In the nonasbestiform variety, mineral crystal growth tend not to grow with parallel alignment, forming multi-directional growth patterns. When pressure is applied, the crystals fracture easily, fragmenting into prismatic particles called cleavage fragments. Some particles or cleavage fragments are acicular or needle-shaped as a result of the tendency of amphibole minerals to cleave along two dimensions but not along the third. Stair-step cleavage along the edges of some particulates is common. Serpentines have a single cleavage direction and single crystals would form sheets when crushed. Serpentine rock, when crushed, will produce some elongated fragments.

Comminution of nonasbestiform amphibole produces particles that, although generally elongated, have widths that are larger than asbestos fibers of the same length. These wide widths are characteristic of all amphibole cleavage fragments, even those that have developed higher aspect ratios due to well-developed parting. Byssollite, the most acicular, needle-like nonasbestiform amphibole, will break perpendicular to the fiber axis during comminution because it is brittle, thereby producing particulates with low aspect ratios (See Reference Exhibit 5).

NON-ASBESTIFORM VARIETY

SERPENTINE GROUP	
antigorite	(CAS No. 12135-86-3)
AMPHIBOLE GROUP	
riebeckite	(CAS No. 17787-87-0)
grunerite	(CAS No. 14567-61-4)
anthophyllite	(CAS No. 17068-78-9)
tremolite	(CAS No. 14567-73-8)
actinolite	(CAS No. 13768-00-8)

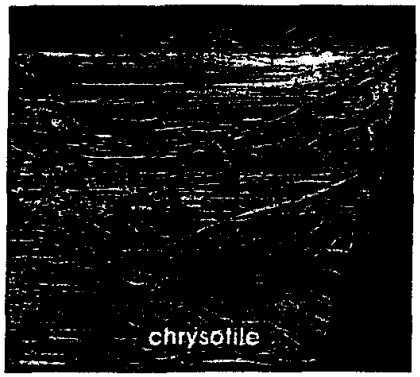
REFERENCE EXHIBIT 2

Macroscopic Raw Ore Comparisons

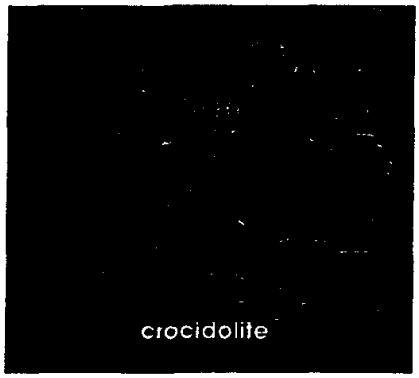
Each of these six minerals included in OSHA's asbestos standard occurs in both an asbestiform and a nonasbestiform variety.

Three of the six minerals have been given a different name for each of their two forms. *Chrysotile* is the asbestiform variety of the serpentine minerals group. In this group *antigorite* is a common nonasbestiform mineral. In the amphibole group, *crocidolite* is the asbestiform variety of *riebeckite*; *amosite* is the asbestiform variety of "cummingtonite"-grunerite.

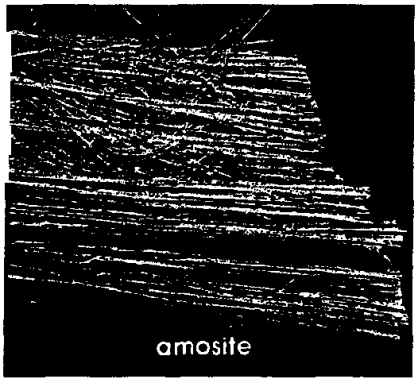
Asbestiform | **Nonasbestiform**

a. 

b. 

c. 

d. 

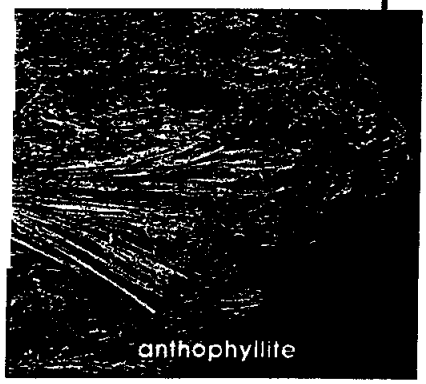
e. 

f. 

The other three minerals — because they occur in their asbestiform varieties so rarely in nature — are each called by only *one* name, regardless of their form.

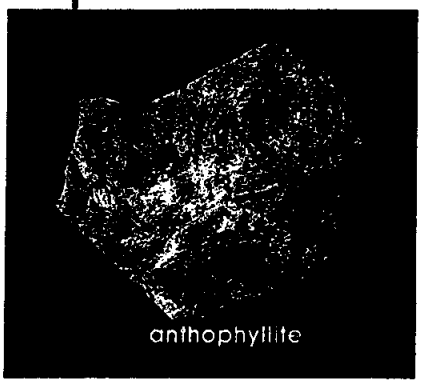
Same Names

Asbestiform

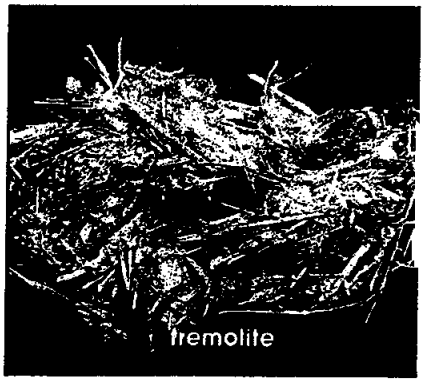


g.

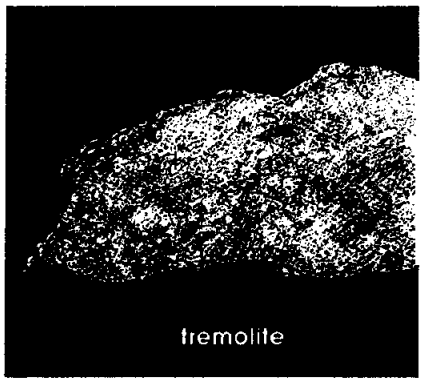
Nonasbestiform



h.

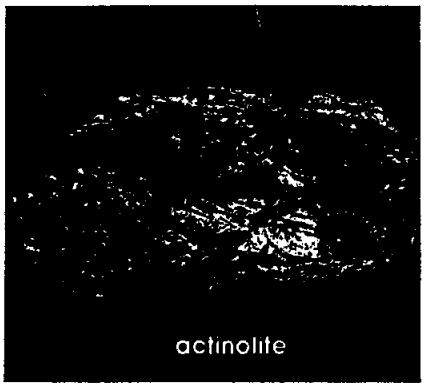


i.



j.

k.



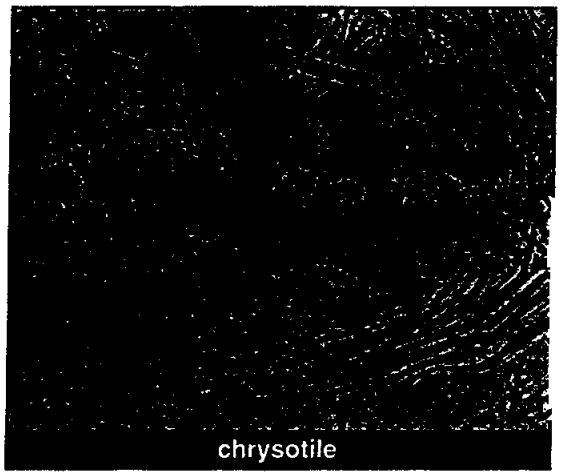
l.

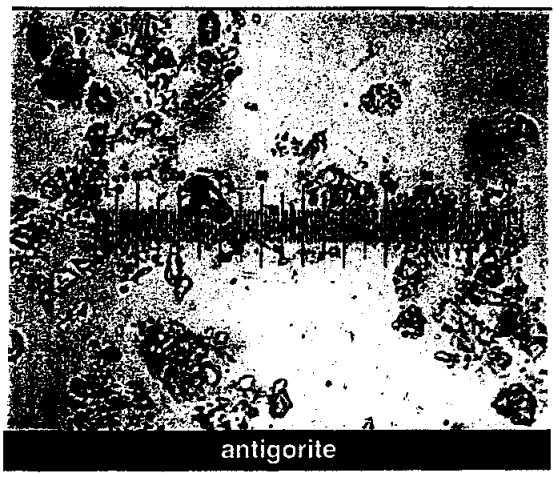
REFERENCE EXHIBIT 3

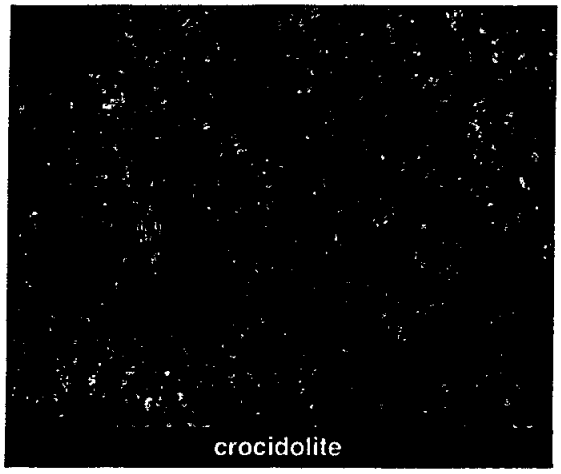
Light Microscopic Comparisons

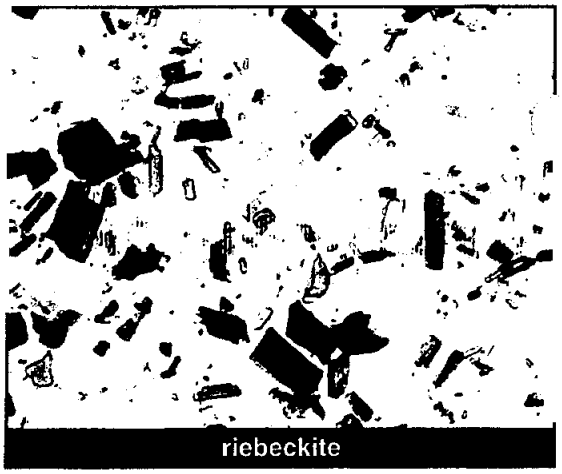
(2.75 µm/divisions)

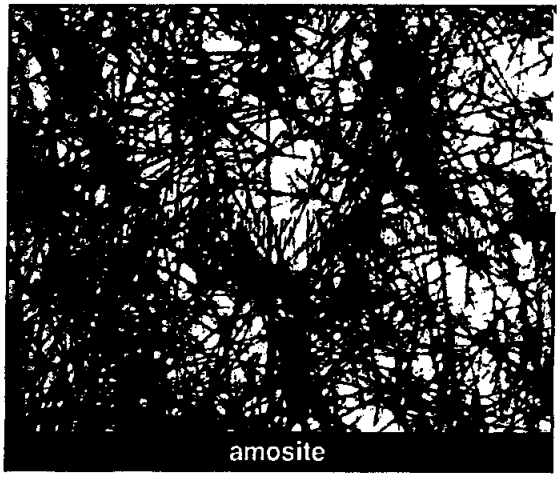
Asbestiform | **Nonasbestiform**

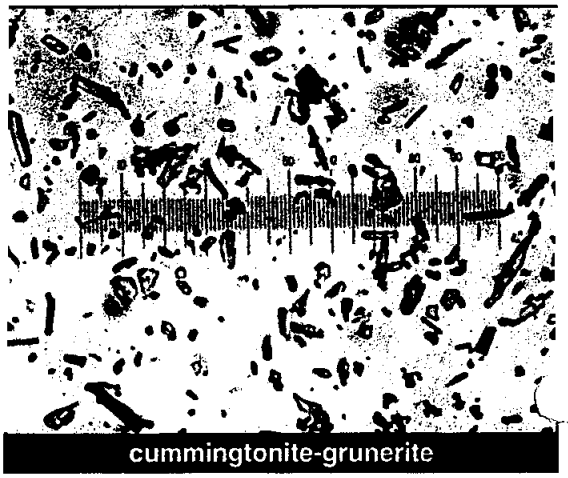
a. 

b. 

c. 

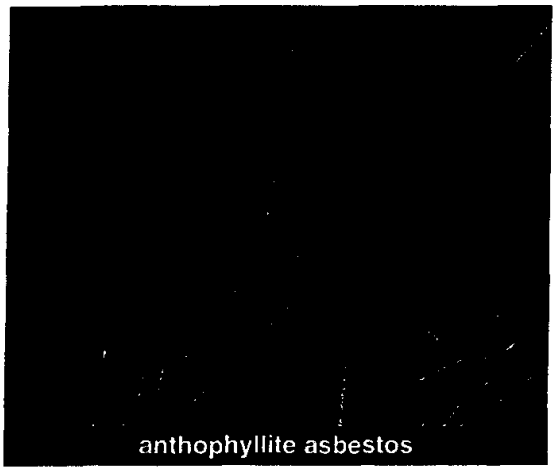
d. 

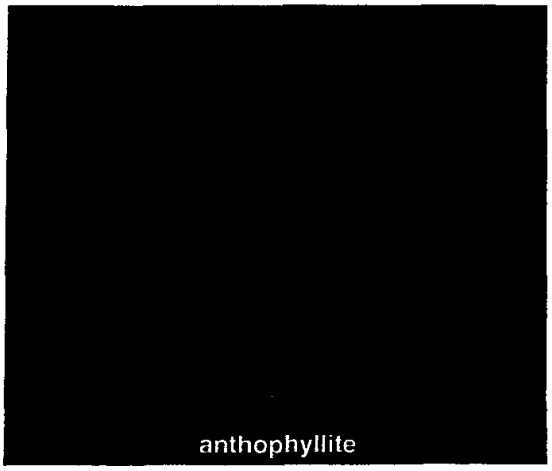
e. 

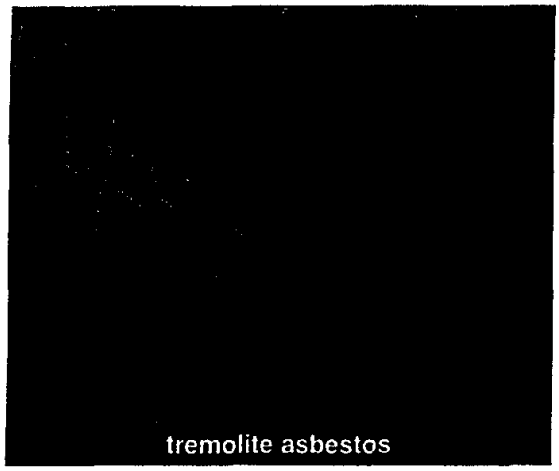
f. 

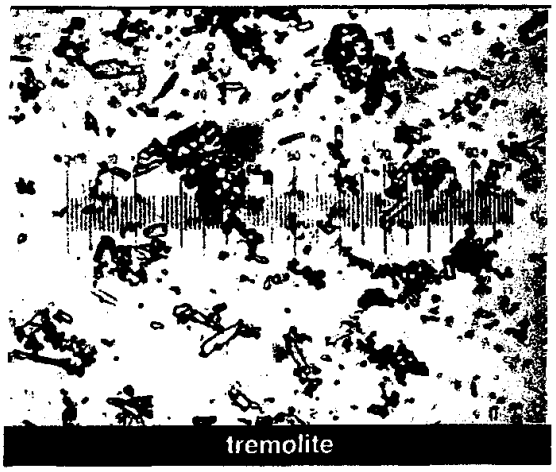
(2.75 µm/divisions)

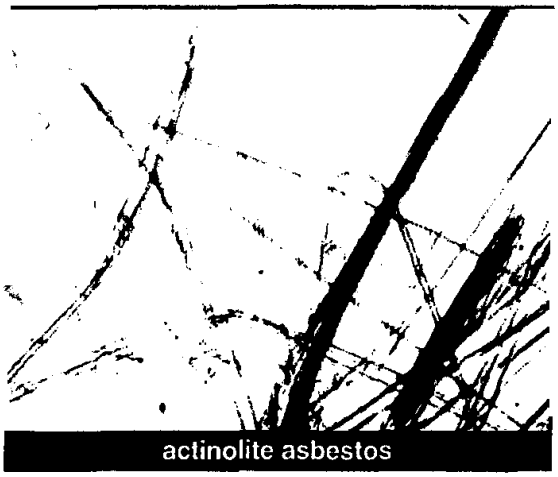
Asbestiform | **Nonasbestiform**

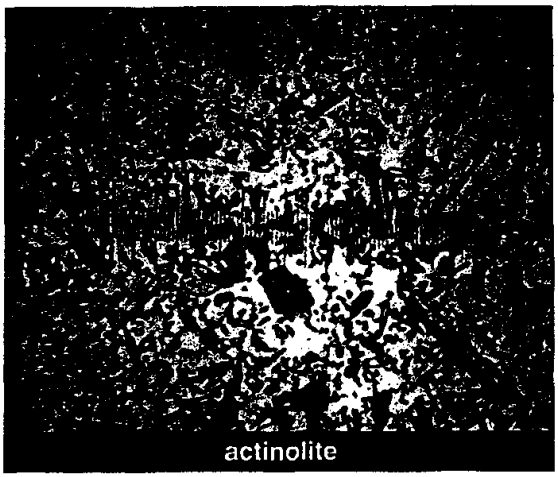
g. 

h. 

i. 

j. 

k. 

l. 

REFERENCE EXHIBIT 4

The Aspect Ratio

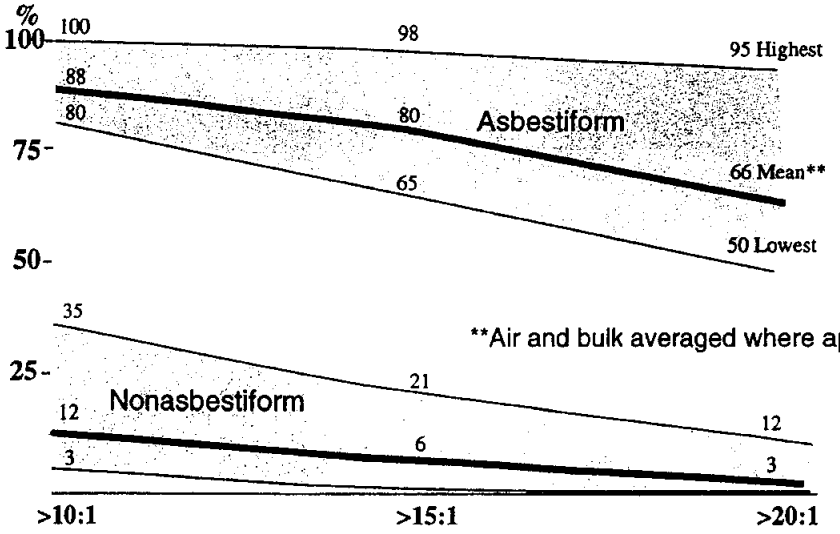
Existing regulatory standards for asbestos are based on a light microscopy analysis of airborne particles with a length-to-width ratio (aspect ratio) of 3:1 or greater and a length greater than 5 µm. This was arbitrarily set to obtain consistency among **asbestos** "fiber" counters. Unfortunately, this dimensionless parameter, adopted for asbestos quantification, has been misused by some as a means to "identify" asbestos. Since many other particles share these dimensions, it is improper to use the aspect ratio as a designator of asbestos.

However, the aspect ratio concept, when used with caution, can be useful in distinguishing the asbestiform or nonasbestiform nature of a given dust population. Due to the tendency of asbestiform fiber bundles to separate into thinner and thinner fibers when pressure is applied (i.e., ground), the aspect ratio tends to remain high. In contrast, because nonasbestiform minerals break or cleave in a more random fashion, few relatively long, thin particles are produced. Nonasbestiform dust populations will, therefore, generally retain low aspect ratio characteristics. This fundamental difference can be observed under the light microscope and used as one analytical parameter to distinguish an asbestiform dust population from a nonasbestiform dust population. It must be stressed, however, that this parameter is not a means to positively identify asbestos.

The following figure contrasts the typical aspect ratio difference between asbestiform dust populations and nonasbestiform dust populations. Starting with all particles that exceed a 3:1 aspect ratio (> 5 µm length), the asbestiform dust population maintains an elevated percentage of high aspect ratio particles while the nonasbestiform population does not.

COMPOSITE ASPECT RATIO DISTRIBUTION*
(from references 5 - 12)

*Aspect ratio for particles >5µm length and an aspect ratio of 3:1 or greater.



**Air and bulk averaged where applicable.

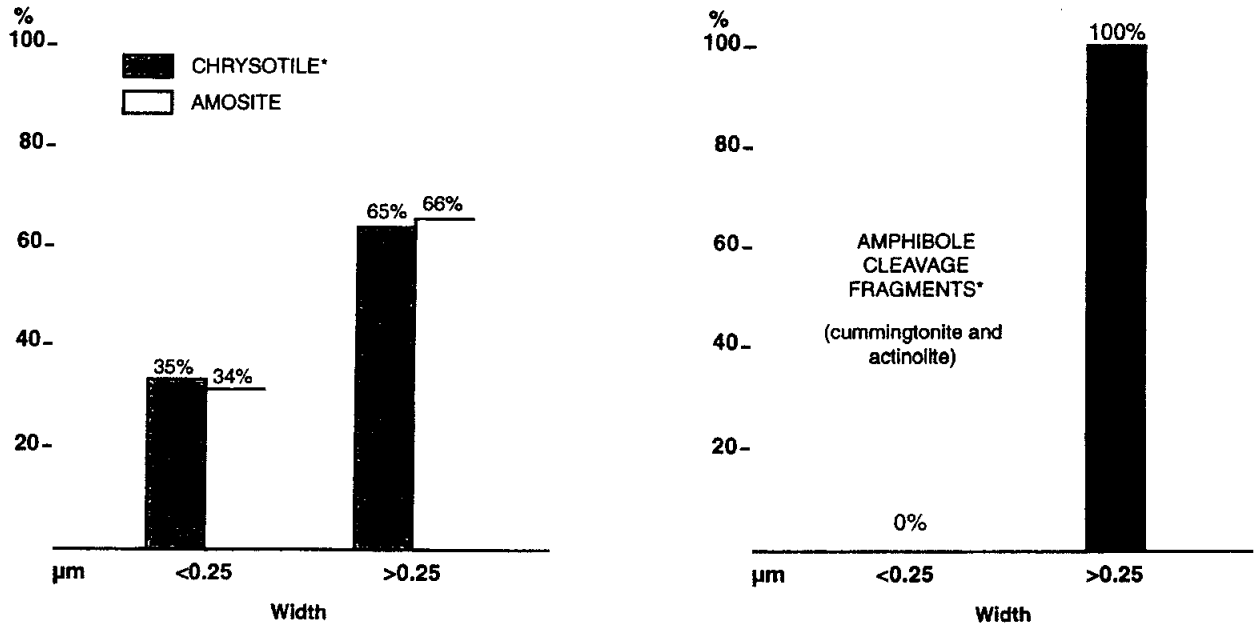
Example: Nonasbestiform particles with an aspect ratio of 3:1 or greater (> 5 µm length), 6% on average exceed an aspect ratio of 15:1 while asbestiform particles, 80% on average exceed this ratio.

Particle Width

Distinctions between populations of cleavage fragments and asbestos fibers can be drawn by comparing the frequency of widths for particles longer than 5 µm. In cleavage fragment populations, width increases with length; in asbestos populations, width is almost independent of length. Cleavage fragments are rarely less than 0.5 µm in width and almost never less than 0.25 µm. A significant fraction of asbestos fibers, however, are less than 0.25 µm in width, and most asbestos populations have at least 50% of the fibers with widths equal to or less than 0.5 µm. (75)

Since asbestos fibrils separate easily, wide fibers composed of multiple fibrils are uncommon in airborne populations or in laboratory preparations that involve dispersal in water by using ultrasound. Nonetheless, there is a slight tendency for very long fibers to be composed of more than one fibril and therefore to be slightly wider than the shorter fibers. In the examination of bulk asbestos under the light microscope, however, it is not uncommon to encounter very wide bundles since sample preparation does not involve fibrillar separation by sonication. However, the composite nature (fibrillar structure) of fibers wider than 1 µm can almost always be seen by light and electron microscopy.

Asbestos populations do vary in their fibril size, the range in fibril size, and their resistance to separation. For example, amosite fibrils are slightly wider than crocidolite fibrils and single fibrils of chrysotile have uniform widths. Nonetheless, taken as a group, the width distribution of a given dust population can be used to gauge the asbestiform or nonasbestiform nature of a mineral dust.

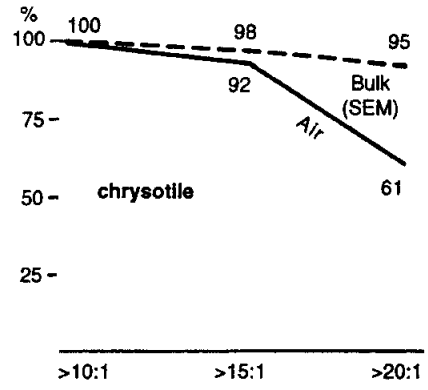


Average of 17 air samples. Width comparison by electron microscopy (STEM). All particles are 3:1 aspect ratio or greater, > 5 µm length (4).

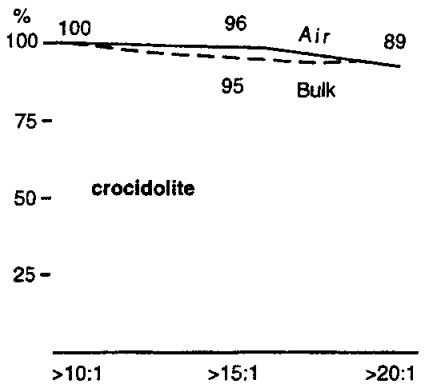
ASPECT RATIO COMPARISONS

Includes only particles with a 3:1 aspect ratio (a.r.) or greater and length > 5 µm.

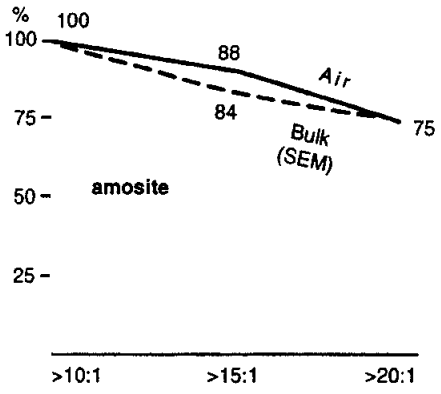
Asbestiform



a. a.r. References: 5,6

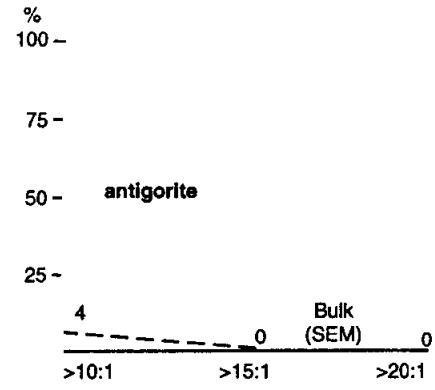


c. a.r. References: 5,7

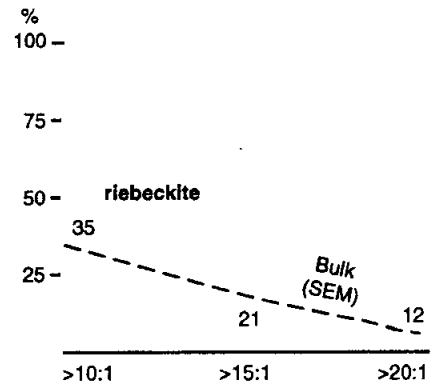


e. a.r. References: 5,7

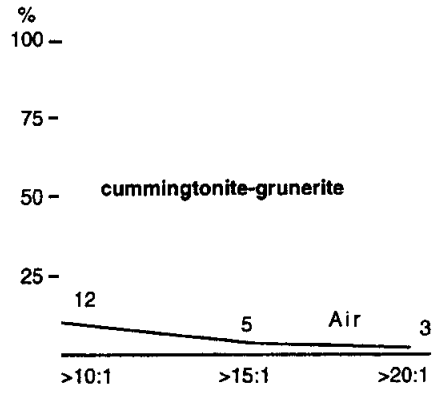
Nonasbestiform



b. a.r. References: 5

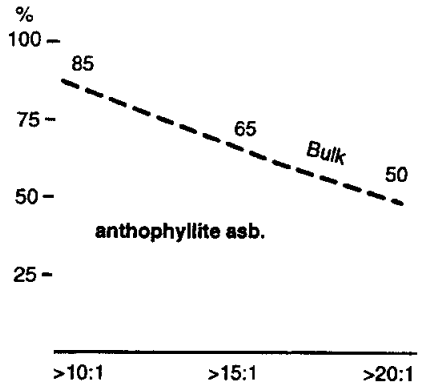


d. a.r. References: 8

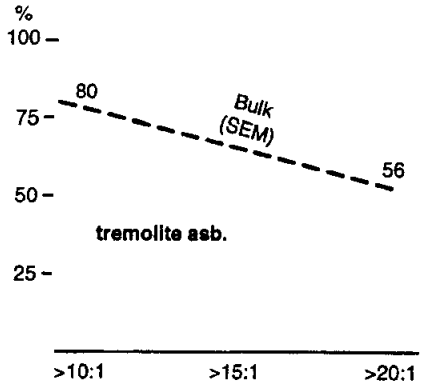


f. a.r. References: 9,10

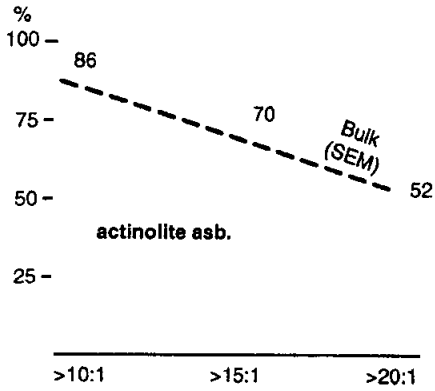
Asbestiform



g. a.r. References: 11

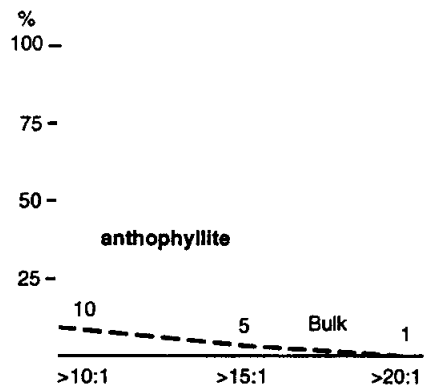


i. a.r. References: 12

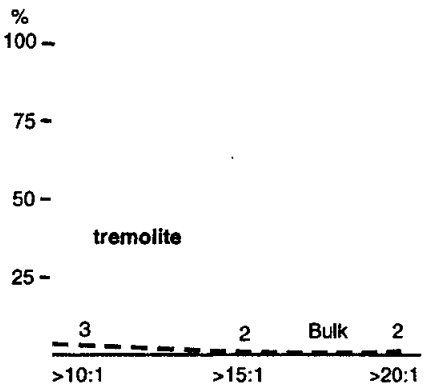


k. a.r. References: 8

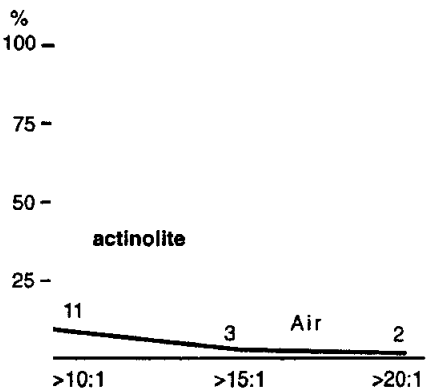
Nonasbestiform



h. a.r. References: 11



j. a.r. References: 5



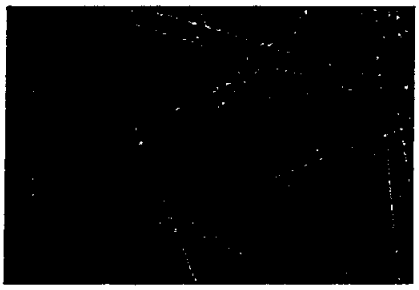
l. a.r. References: 5

REFERENCE EXHIBIT 5

Bysollite
Unusual Needle-like Nonasbestiform Mineral Growth

Although most nonasbestiform particulates appear as described and pictured in prior exhibits, nonasbestiform particles can appear in a very acicular or needle-like form. Although such particles do not exhibit characteristics unique to asbestos (fibrillar bundling, spayed terminations, extreme lengths, etc.), high length to width aspect ratios are possible. The Addison Italian and Domie tremolite samples summarized in this pictorial exhibit (J and P respectively) reflect this rare particulate form.

Further comminution of these elongated nonasbestiform particles, as illustrated below, demonstrates the essential difference in mineral habit. Nonasbestiform minerals cleave to shorter prismatic particles, while asbestos continues to separate along crystal surfaces into smaller and smaller bundles of fibrils.



Photomicrograph - 265 X (2 µm/Div.)

Minor Breaking
Photomicrograph - 265 X (2 µm/Div.)

Commercial Grind
Photomicrograph - 265 X (2 µm/Div.)

QUESTION

DOES THIS MINERALOGICAL (MORPHOLOGICAL) DIFFERENCE = BIOLOGICAL DIFFERENCE?

A Review of
Asbestiform and Nonasbestiform Cancer Studies

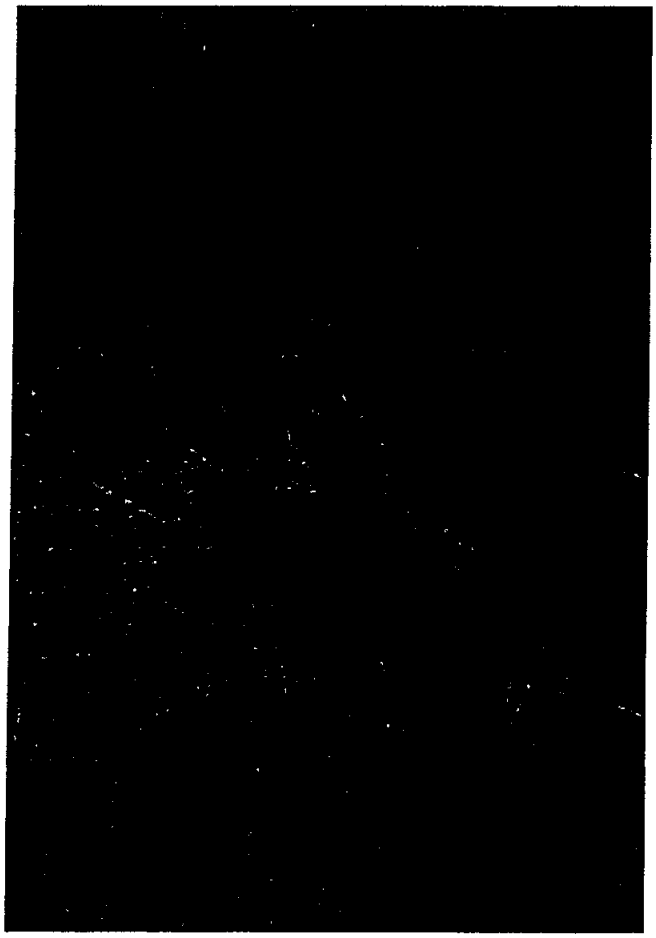
The following "EXPOSURE EXHIBITS" summarize human and animal studies relative to nonasbestiform amphiboles. The majority of studies available in this area involve tremolite.

A large body of literature amply addresses the most commonly encountered, commercially exploited asbestos minerals (*chrysotile*, *crocidolite*, and *amosite*). For the purpose of this presentation, further health review of these asbestos minerals is not considered necessary.

These asbestiform exhibits sufficiently demonstrate previously described mineralogical distinctions and provide the most appropriate contrast to nonasbestiform amphibole health studies.

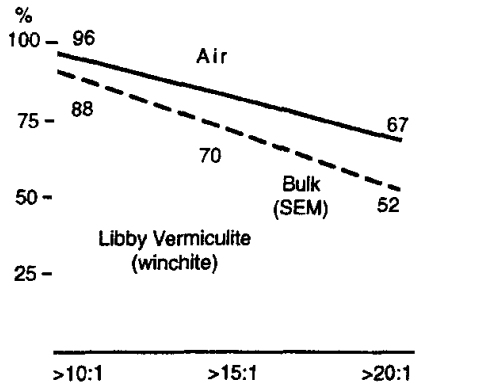
Asbestiform Winchite — Human Mortality Study

Light Microscopy: 320 X

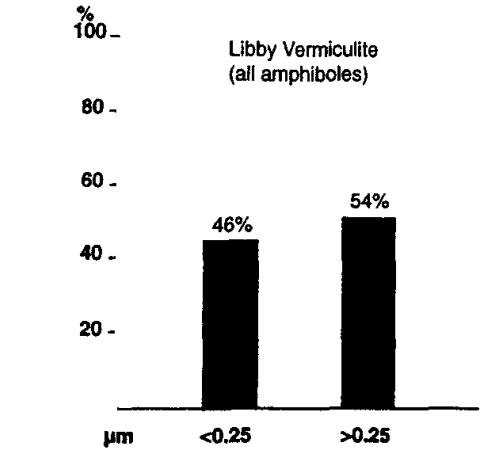


SEM: 1180 X

ORE: "The vermiculite ore as fed to the mill contained 4-6% amphibole in the tremolite series" (13). More recent analysis of the Libby ore reports the asbestiform amphibole to be winchite asbestos (formally called soda tremolite) (74).



Aspect Ratio Reference: 14,15



Width Reference: 16

ADDITIONAL MINERAL PARTICLE DATA:

Range of: Diameters = 0.1 - 0.2 µm
Length = 1 - 70 µm (62% > 5 µm)
Aspect Ratio = 3:1 - 100:1 (13)

For fibers > 0.45 µm in width and > 5 µm in length, collected on air filters, 96% had aspect ratios > 10:1, 67% had 20:1 or greater aspect ratios and 10% were 50:1 or greater. (15)

HEALTH STUDIES:

Authors: McDonald, J.C., et al (13) Pub. 1986
Cohort: 406 men, >1 yr. exposure, hired prior to 1963
Vital Status Cut Off: July 1, 1983 **SMR** (resp. cancer) - 245
Conclusion: "The cohort studied was not large but sufficient to show that workers in this mine experienced a serious hazard from lung cancer, pneumoconiosis, and mesothelioma."

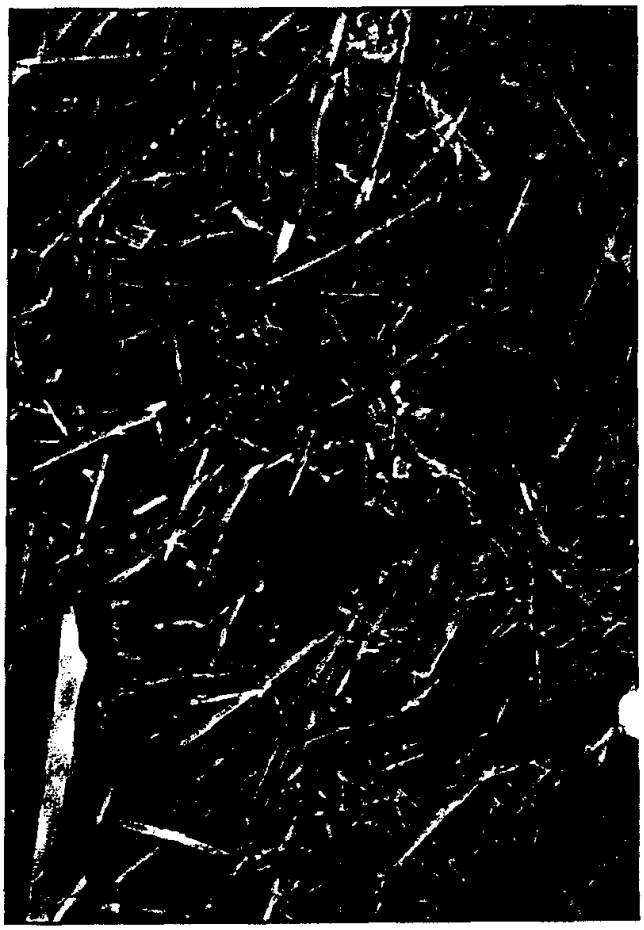
Authors: Amandus, H.E., et al (15) Pub. 1987
Cohort: 575 men, >1 yr. exposure, hired prior to 1970
Vital Status Cut Off: December 31, 1981 **SMR** (resp. cancer) - 223
Conclusion: "Results indicated that mortality from nonmalignant respiratory disease and lung cancer was significantly increased."

OVERALL CONCLUSION: **Asbestiform winchite in this mining operation is reasonably linked to excess lung cancer and mesothelioma.**

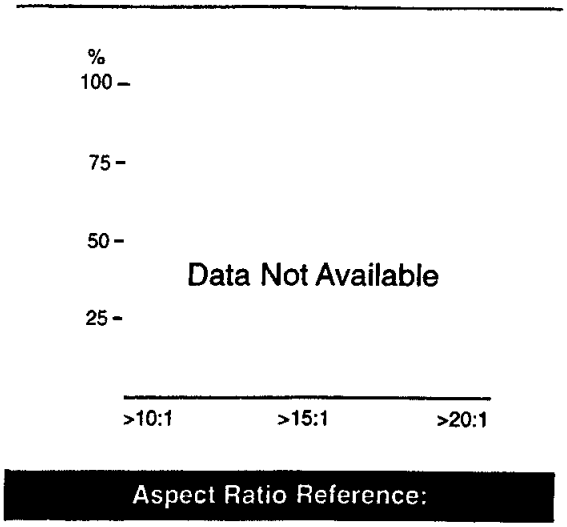
Asbestiform Tremolite — Human Mortality Study

Light Microscopy: 320 X

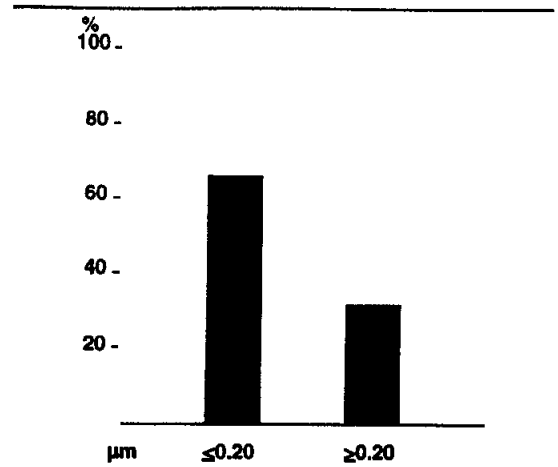
SEM: 1900X



ORE: "This tremolite is linked to whitewash used in Greek villages. The villages involved Milea, Metsovo, Anilio and Votonosi (Metsovo area in North Western Greece)" (18).



Aspect Ratio Reference:



Width Reference: 17

ADDITIONAL MINERAL PARTICLE DATA:

"These fine fibers were unlike the usual tremolite laths, they had aspect ratios in excess of 100:1; they were curvilinear; they had parallel extinction, and they formed polyfilamentous bundles of fibers" (18). Only 6.7% of fibers exceeded a 0.61 µm width. Fifty-three percent of all fibers were < 1.0 µm in length while 6% exceeded 5 µm in length (17).

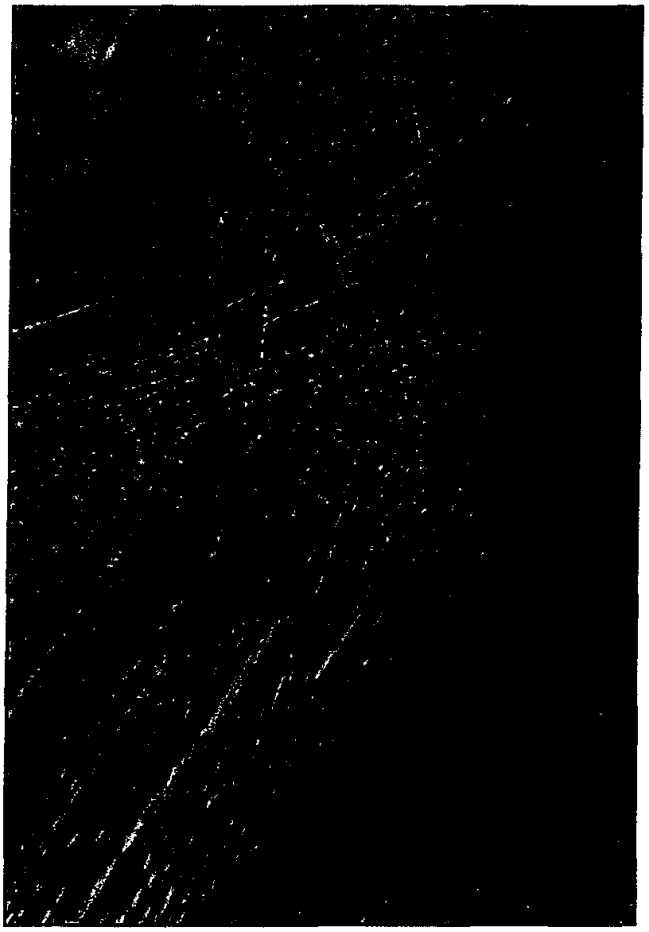
HEALTH STUDIES:

Authors: Langer, A.M., et al (18) Pub. 1987
Cohort: Population of Metsovo in Northwestern Greece
Conclusion: Substantial incidence of mesothelioma in certain towns is linked to tremolite asbestos found in whitewash and stucco.

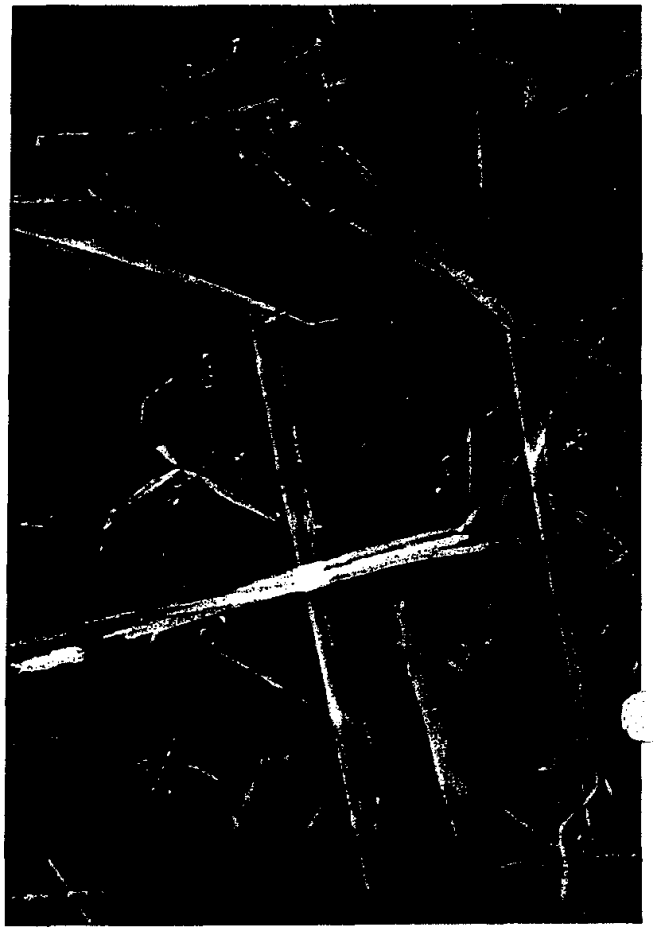
OVERALL CONCLUSION: **Asbestiform tremolite in whitewash has been linked to substantial incidences of mesothelioma.**

Asbestiform Tremolite — Animal Study

Light Microscopy: 320 X



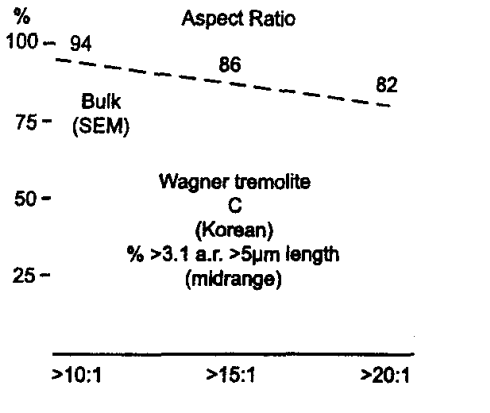
SEM: 1900 X



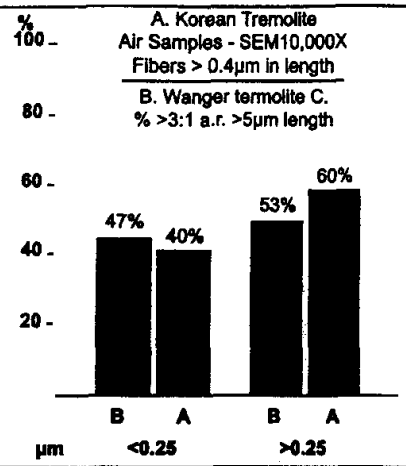
SAMPLE: Reported as commercial asbestos originating from S. Korea. Contains by mass approx. 95% asbestiform tremolite. It is reported this same material was used in three separate animal studies (19).

ADDITIONAL MINERAL PARTICLE INFORMATION

"In the optical microscopy and SEM examinations, the asbestos tremolites were found to be typical of that form in displaying polyfilamentous fiber bundles, curved fibers, fibers with splayed ends, and long, thin, parallel-sided fibers. Most of the fibers showed straight extinction when observed with polarized light under crossed polarizers, indicating the presence of multiple twinning of the crystals." "Samples did contain some elongated fragments of tremolite with oblique extinction, stepped ends, and nonparallel sides indicating that they were cleavage fragments." (20)



Aspect Ratio Reference: 22,23



Width Reference: 21, 22, 23

ANIMAL STUDIES:

Authors: Wagner, J.C., et al (22) Pub. 1982
Test Animals: Sprague-Dawley rats, 6-10 weeks old when injected.
Test Type: Pleural injection
Protocol: A single 20 milligram injection into the right pleural cavity of 48 rats. "The sample was prepared by milling in a small agate mill and ultrasonic dispersion, large particles being removed by sedimentation in water."
Findings: "Sample C produced 14 mesotheliomas in 47 rats."

Authors: Davis, J.M., et al (21) Pub. 1985
Test Animals: SPF male Wistar rats
Test Type: Inhalation and interperitoneal injection
Protocol: For inhalation, 48 rats were exposed for 7 hours each day, 5 days per week, over a 12 month period, to approx. 10 mg of respirable dust per cubic meter of air. For interperitoneal injection, a 25 mg dose of tremolite was collected from the inhalation chamber and injected (in saline) into the peritoneal cavities of rats.
Findings: For the inhalation study, a total of 16 carcinomas and 2 mesotheliomas occurred in 39 animals. None were observed in controls. For the interperitoneal study, a total of 27 animals out of 29 examined were found to have mesothelioma tumors. Mean survival time was 352 days.

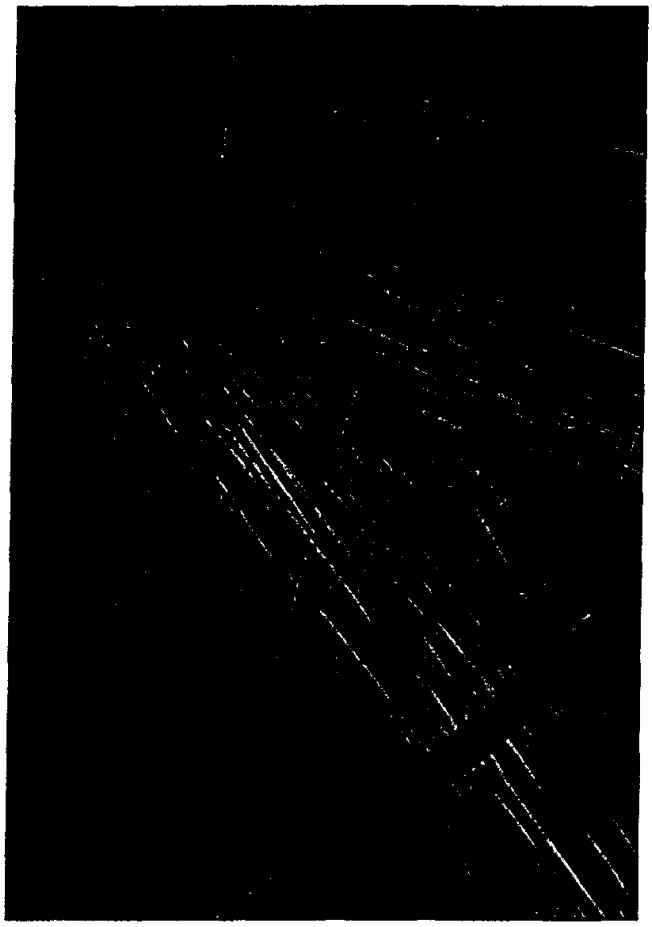
Authors: Davis, J.M.G., Addison, J. (20) Pub. 1991
Test Animals: AF/Han strain rats
Test Type: Peritoneal injection
Protocol: Fractions of this sample were obtained by generating an airborne dust cloud in an experimental chamber (Timbrell dust dispensers) with fine fractions collected using a vertical elutriator. A single 10 mg dose was injected into the peritoneal cavities of the animals. All animals lived out of their full life span or were killed when moribund.
Findings: 32 mesothelioma deaths out of 33 animals were observed with a median survival time of 428 days.

OVERALL CONCLUSION: **This asbestiform tremolite produced a strong carcinogenic response in the test animals.**

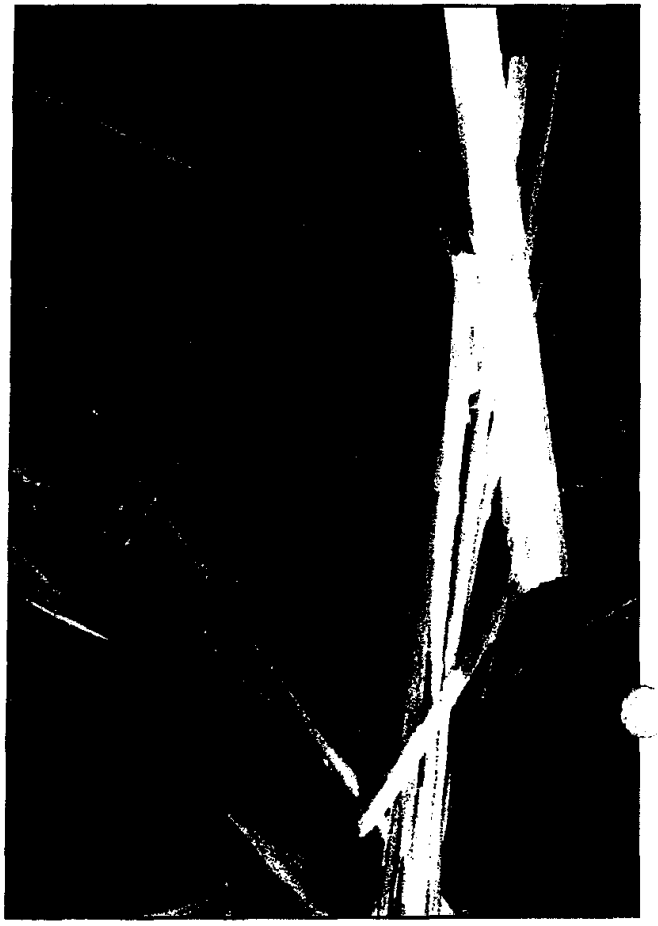
EXPOSURE EXHIBIT D *ADDISON/DAVIS-TREMOLITE (Jamestown)*

Asbestiform Tremolite — Animal Study

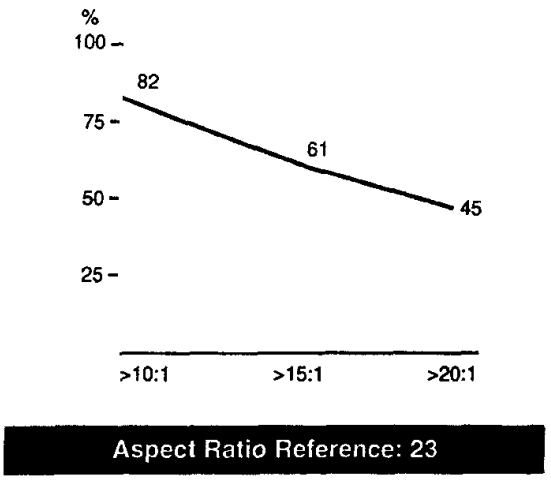
Light Microscopy: 320 X



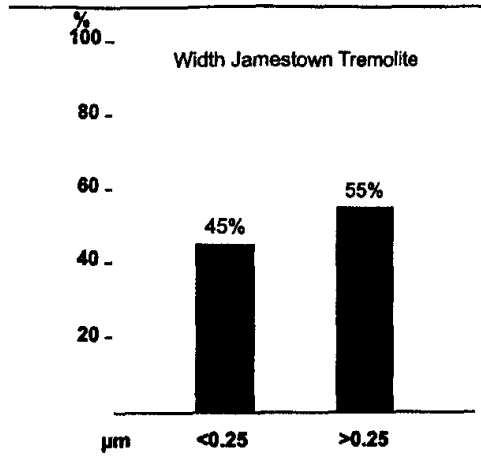
SEM: 1900 X



SAMPLE: "Fine white tremolite asbestos, Jamestown, California" (20). (Above photomicrographs were taken from bulk material.)



Aspect Ratio Reference: 23



Width Reference: 23

ADDITIONAL MINERAL PARTICLE DATA:

"In the optical microscopy and SEM examinations, the asbestos tremolites were found to be typical of that form in displaying polyfilamentous fiber bundles, curved fibers, fibers with splayed ends, and long, thin, parallel-sided fibers. Most of the fibers showed straight extinction when observed with polarized light under crossed polarizers, indicating the presence of multiple twinning of the crystals." "Samples did contain some elongated fragments of tremolite with oblique extinction, stepped ends, and nonparallel sides indicating that they were cleavage fragments." (20)

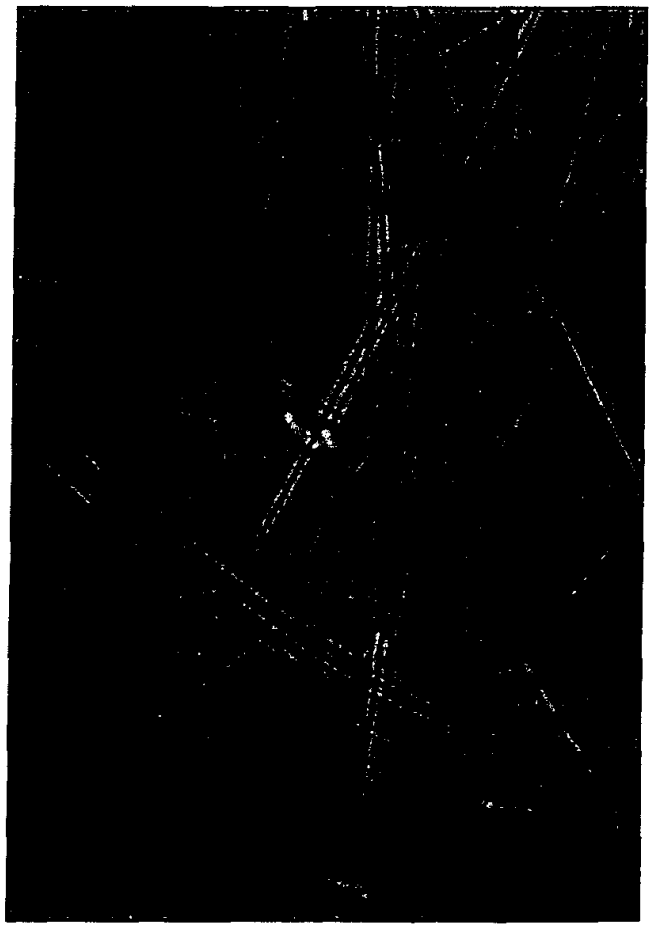
ANIMAL STUDIES

Authors: Davis, J.M.G., Addison, J. (20) Pub. 1991
Test Animals: AF/Han strain rats
Test Type: Peritoneal injection
Protocol: Fractions of this sample were obtained by generating an airborne dust cloud in an experimental chamber (Timbrell dust dispensers) with fine fractions collected using a vertical elutriator. A single 10 mg dose was injected into the peritoneal cavities of the animals. All animals lived out of their full life span or were killed when moribund.
Findings: 36 mesothelioma deaths out of 36 animals were observed with a median survival time of 301 days.

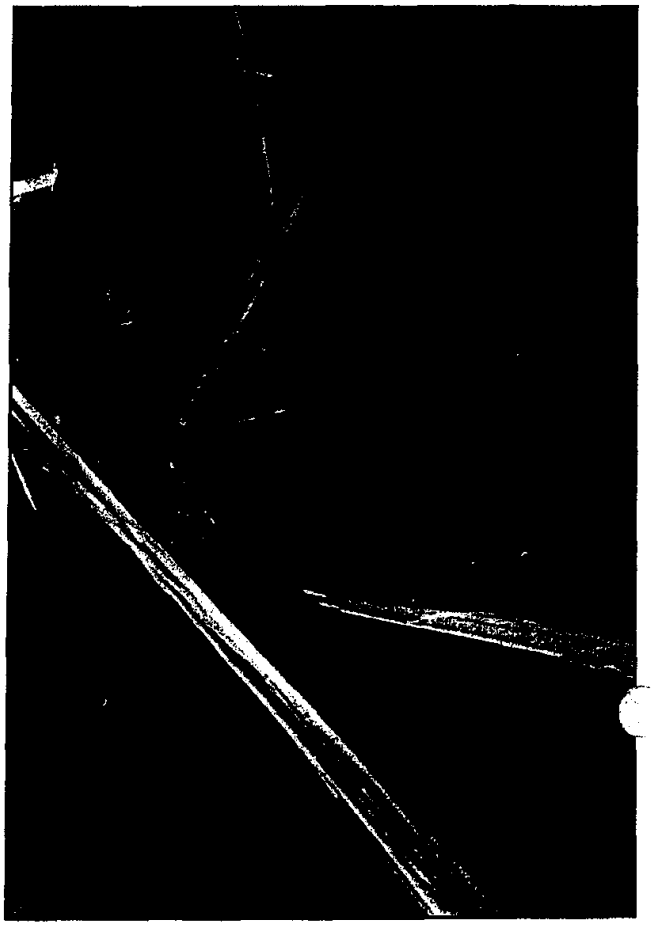
OVERALL CONCLUSION: **This asbestiform tremolite produced a strong carcinogenic response in the test animals.**

Asbestiform Tremolite — Animal Study

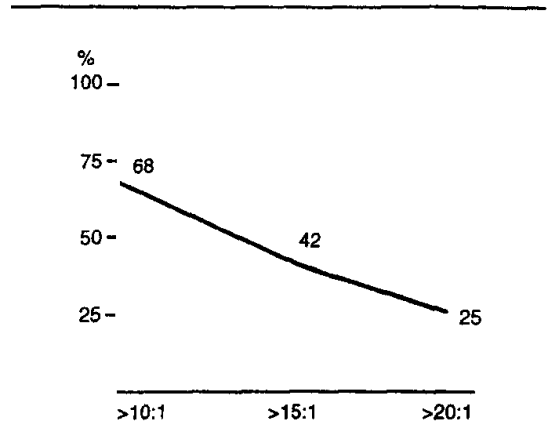
Light Microscopy: 320 X



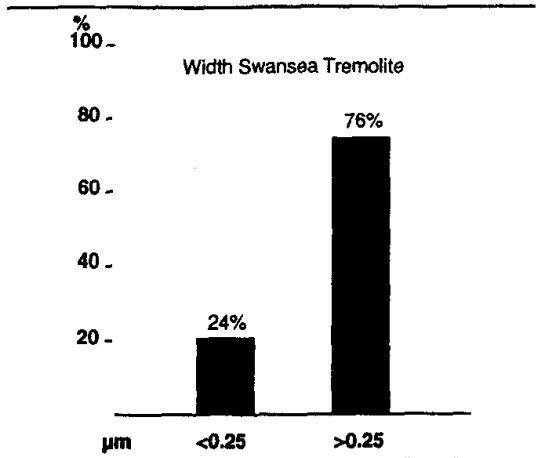
SEM: 1900 X



SAMPLE: "Fine white tremolite asbestos, Swansea Laboratory" (20). (Above photomicrographs were taken from bulk material.)



Aspect Ratio Reference: 23



Width Reference: 23

ADDITIONAL MINERAL PARTICLE DATA:

"In the optical microscopy and SEM examinations, the asbestos tremolites were found to be typical of that form in displaying polyfilamentous fiber bundles, curved fibers, fibers with splayed ends, and long, thin, parallel-sided fibers. Most of the fibers showed straight extinction when observed with polarized light under crossed polarizers, indicating the presence of multiple twinning of the crystals." "Samples did contain some elongated fragments of tremolite with oblique extinction, stepped ends, and nonparallel sides indicating that they were cleavage fragments." (20)

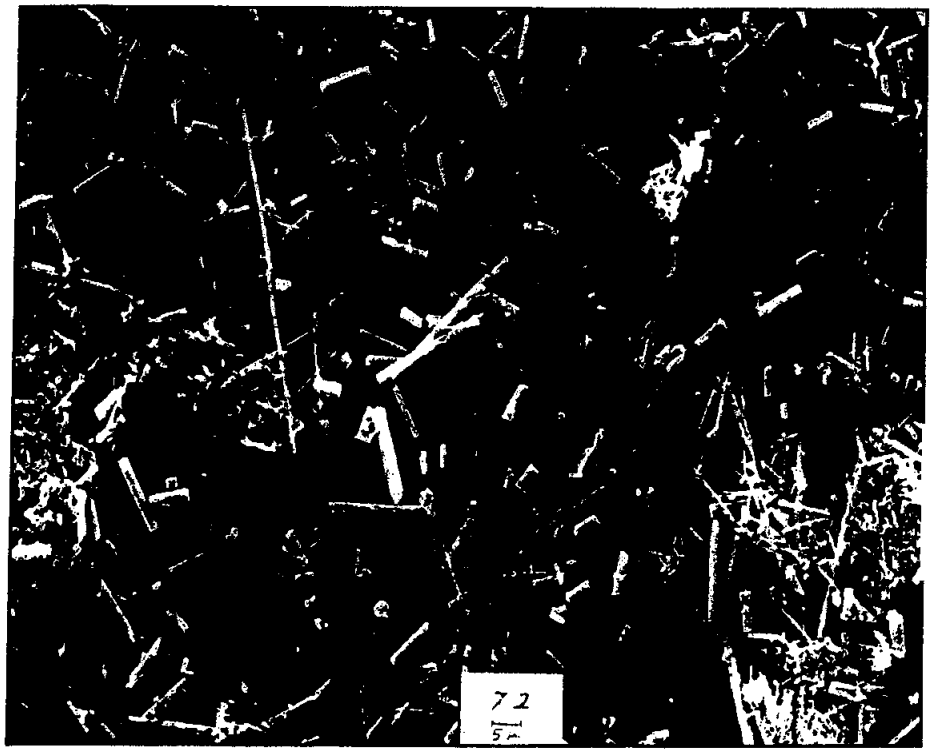
ANIMAL STUDIES

Authors: Davis, J.M.G., Addison, J. (20) Pub. 1991
Test Animals: AF/Han strain rats
Test Type: Peritoneal injection
Protocol: Fractions of this sample were obtained by generating an airborne dust cloud in an experimental chamber (Timbrell dust dispensers) with fine fractions collected using a vertical elutriator. A single 10 mg dose was injected into the peritoneal cavities of the animals. All animals lived out of their full life span or were killed when moribund.
Findings: 35 mesothelioma deaths out of 36 animals were observed with a median survival time of 365 days.

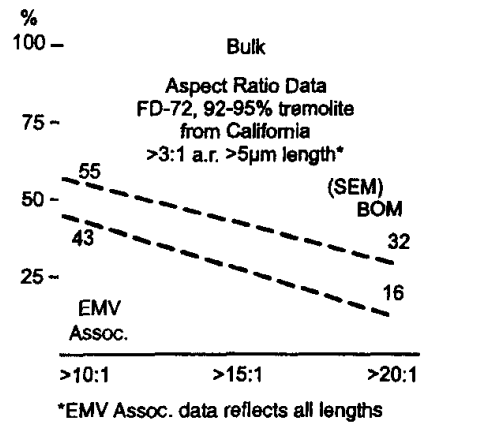
OVERALL CONCLUSION: **This asbestiform tremolite produced a strong carcinogenic response in the test animals.**

Asbestiform Tremolite — Animal Study

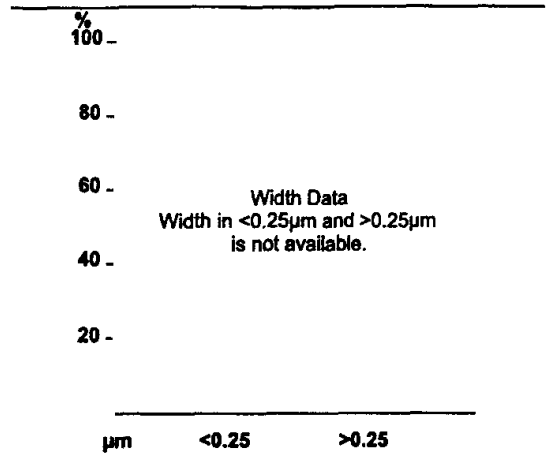
SEM: 1250 X



SAMPLE: FD-72 was supplied to Dr. Smith from Dr. Merle Stanton and indirectly from Johns-Manville. This material, reportedly from California, is described as asbestiform and may have been used by Dr. Stanton in his work, (tremolite 1 and 2).



Aspect Ratio Reference: 12, 24



ADDITIONAL MINERAL PARTICLE DATA:

The sample preparation of FD-72 is unclear although a portion of this sample was provided to the Bureau of Mines (BOM) for characterization. The sample was dispersed in water, ultrasonically agitated and filtered through a nucleopore filter for SEM preparation. Petrographic preparation required no such processing. There is some question as to how exact the BOM samples are to Dr. Smith's analysis (EMV Assoc), but major differences are not indicated. For FD-72, 9 particles with a length of >10 µm were observed in 200 total particles by SEM.

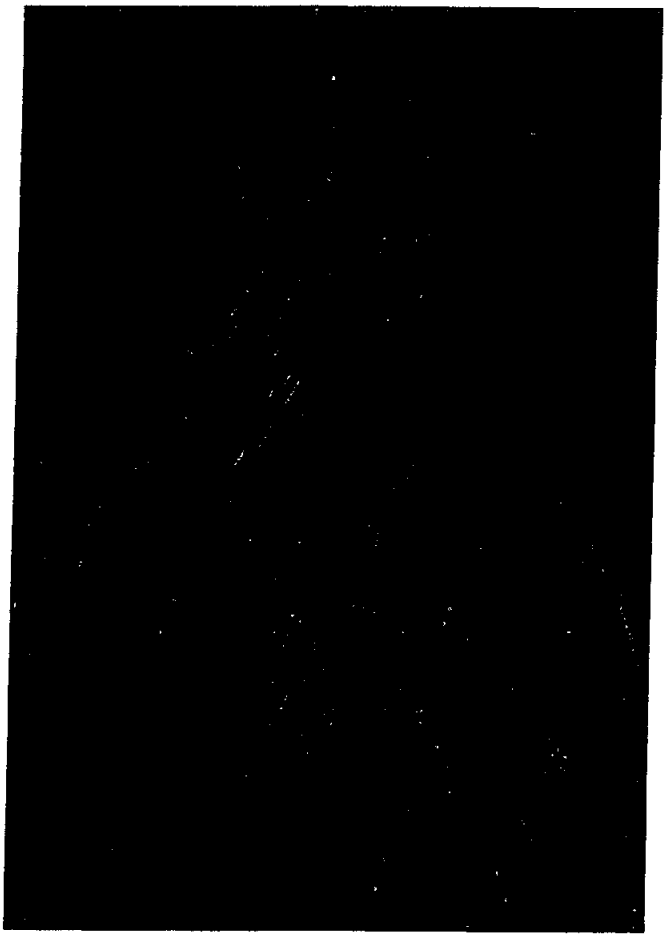
ANIMAL STUDIES

Authors: Smith, W.E., et al (25) Pub. 1979
Test Animals: Male LUG: LAK hamsters, injected at 2 months of age.
Test Type: Intrapleural injection
Protocol: Single intrapleural injection of two dosages (10 and 25 mg). The sample was suspended in saline and sterilized by autoclave. The occurrence of tumors (unspecified) was noted at necropsies for a starting group of 50 animals per dose. After short-term sacrifice of some animals and the loss of others through acute enteritis, the occurrence of tumors was noted in nonsurvivors up to 600 days.
Findings: Four tumors out of 13 animals were found at the 10 mg dose, and 13 out of 20 animals were found at the 25 mg dose.

OVERALL CONCLUSION: **Asbestiform tremolite produced pleural tumors.**

Asbestiform Tremolite — Animal Study

Light Microscopy: 320 X



SEM: 1800 X

SAMPLE: The exact origin of this tremolite asbestos from California, provided to Dr. Stanton by Johns-Manville is unknown (26). "Both of these samples were from the same lot of asbestos and were in the optimal range of size for carcinogenesis" (27).

Aspect Ratio and Width Data

Aspect ratio and width data has not been developed due to concerns over the reliability of transcribing data presented in the literature (28). These difficulties result from questions over the accuracy (reproducibility) of size distribution data (especially for asbestiform samples — see discussion below). Size-data, however, does reflect a broad size distribution with many very long and very narrow fibers (i.e., < 0.25 width, > 20:1 aspect ratios).

ADDITIONAL MINERAL PARTICLE DATA:

Obtaining accurate dimensional data for these tremolite samples was difficult as reported by the investigators on Page 965 of their report: "Of special interest are the data on the amphibole asbestoses: amosite, tremolite and crocidolite, though estimates of the dimensions of the asbestoses are especially liable to error." And on Page 973: "In preparations of amphibole asbestos (which included the crocidolites and tremolites), we observed that both clumping and fragmentation of the particles were greater than those in other minerals, and estimates of particle size distribution in that the asbestiform characteristic of fiber bundles (reported as clumping), and the splitting of these bundles (reported as fragmentation), was the reason for the difficulty in obtaining accurate fiber size distributions.

ANIMAL STUDIES

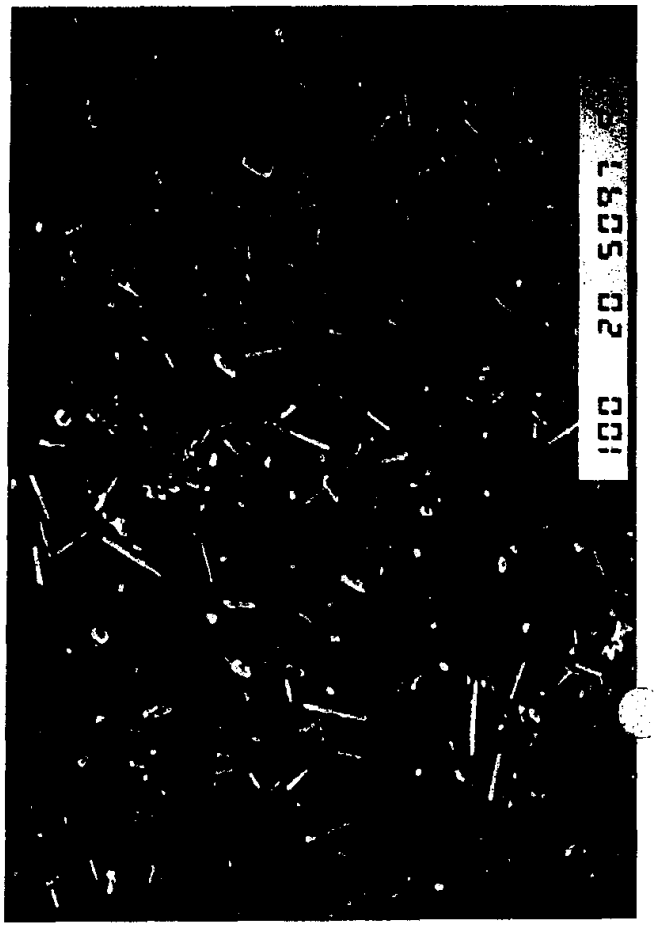
Authors: Stanton, M.F., et al. (27) Pub. 1981
Test Animals: 20-week-old, outbred female Osborne-Mendal rats
Test Type: Pleural implantation
Protocol: A standard 40 mg dose of each tremolite asbestos sample was uniformly dispersed in hardened gelatin and applied by open thoracotomy directed to the left pleural surface. The animals were followed for 2 years, at which time the survivors were sacrificed and the tissue examined for pleural sarcomas.
Findings: Exposure to these tremolite asbestos samples resulted in tumor incidences in 22 out of 28 animals for Sample 1 and 21 out of 28 animals in Sample 2.

OVERALL CONCLUSION: **These asbestiform tremolites resulted in a significant carcinogenic response in the study population.**

Asbestiform Ferroactinolite — Animal Study

Light Microscopy: 400 X

SEM: 200 X



SAMPLE: "Test fibers were prepared from loose surface iron-formation rocks" (29).

NOTE: Although the reference photo-micrograph reflects actinolite asbestos, ferroactinolite is not a designated asbestos mineral. It appears, however, to be asbestiform.

Ferroactinolite Prior to Placement in the Animals			
	Mean	Median	Range
Length	3.18	1.50	0.3 - 52.3
Width	0.41	0.24	0.03 - 5.23
Aspect Ratio	9.0	6.0	3.0 - 130.0

Ferroactinolite After Placement in the Animals			
	Mean After		
	1 Month	4 Months	12 Months
Length	2.10	2.00	1.77
Width	0.19	0.17	0.11
Aspect Ratio	17.1	22.3	30.1

ADDITIONAL MINERAL PARTICLE DATA:

"The estimated mineral particle content by volume was as follows: ferroactinolite fibers (50%), sheet silicate plates (20%), magnetite (5%), ferroactinolite and hornblende fragments (20%), and other minerals (5%)" (29). "Examination by transmission electron microscopy of low temperature ashed whole lung specimens of animals killed sequentially, indicated that the mineralogical characteristics of both ferroactinolite and amosite fibers changed in time. Longitudinal splitting of the fibers resulted in a greater number of thinner fibers with increased aspect ratio." "The ferroactinolite splitting reaction is more rapid and results in the formation of thinner and more numerous fibers than the amosite splitting reaction" (30).

ANIMAL STUDIES

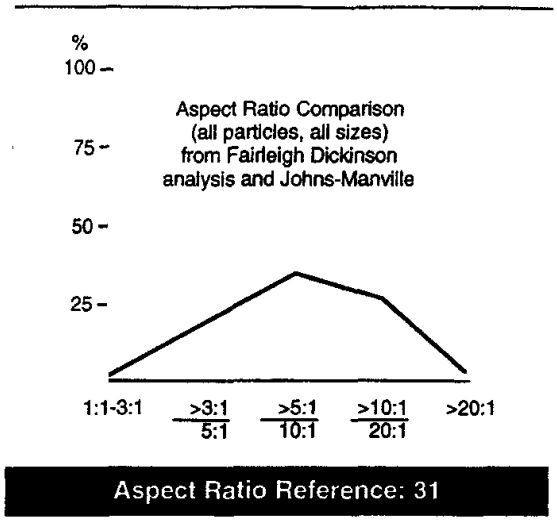
Authors: Cook, P.M., Coffin, D.L., et al (29-30) 1982
Test Animals: Male Fischer - 344 rats
Test Type: Intratracheal instillation and intrapleural injection
Protocol: The intratracheal instillation experiment involved twelve week injections of 0.5 and 0.25 mg each in groups of 561 and 139 rats (ferroactinolite and amosite, respectively). For study of early pathological sequences and for the evaluation of clearance and fate of mineral fibers by electron microscopy, the animals were killed at various intervals up to 1 year, while others were allowed to live out their lives. The intrapleural injection experiment involved a single injection of 20 mg in groups of 135 and 137 rats. Animals were allowed to live out their lives.
Findings: "The data demonstrates that ferroactinolite produced neoplastic lesions through both routes of inoculation. On the basis of mass dose by intratracheal instillation on cogenic potency, it was greater for the ferroactinolite, whereas, by intrapleural inoculation, potency was greater for amosite, however, the difference was not statistically significant."

OVERALL CONCLUSION: **This study demonstrates a carcinogenic effect to asbestiform ferroactinolite.**

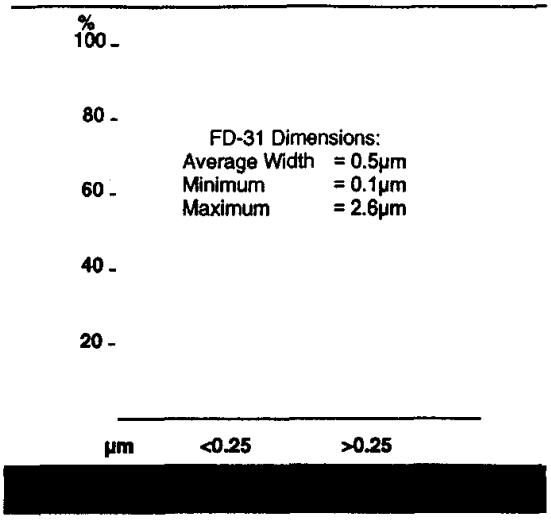
Asbestiform or Highly Fibrous Tremolite — Animal Study

SEM: 1250 X

SAMPLE: FD-31 was provided through Johns-Manville Corp. from a tremolitic talc in the Western United States (JM Sample 4368-31-3). The exact origin of this sample is unknown. This sample is generally considered a mineralogical curiosity.



Aspect Ratio Reference: 31



ADDITIONAL MINERAL PARTICLE DATA:

The exact origin and preparation of this sample is unclear. Subsequent analysis of this sample suggests that: "The particle distribution in the sample is not typical of cleavage fragments of tremolite. The particles in Sample 31 appear to be composed of true fibers whose shape was attained by growth rather than cleavage." "Particles with a 20:1 aspect ratio are quite common." "There is at least one particle which appears to be a bundle of fibers although the photograph is too fuzzy to be absolutely sure,. . ." "This sample is probably not true asbestos, and would be more appropriately characterized as a stiff fibrous variety of amphibole, which is probably byssollite" (32).

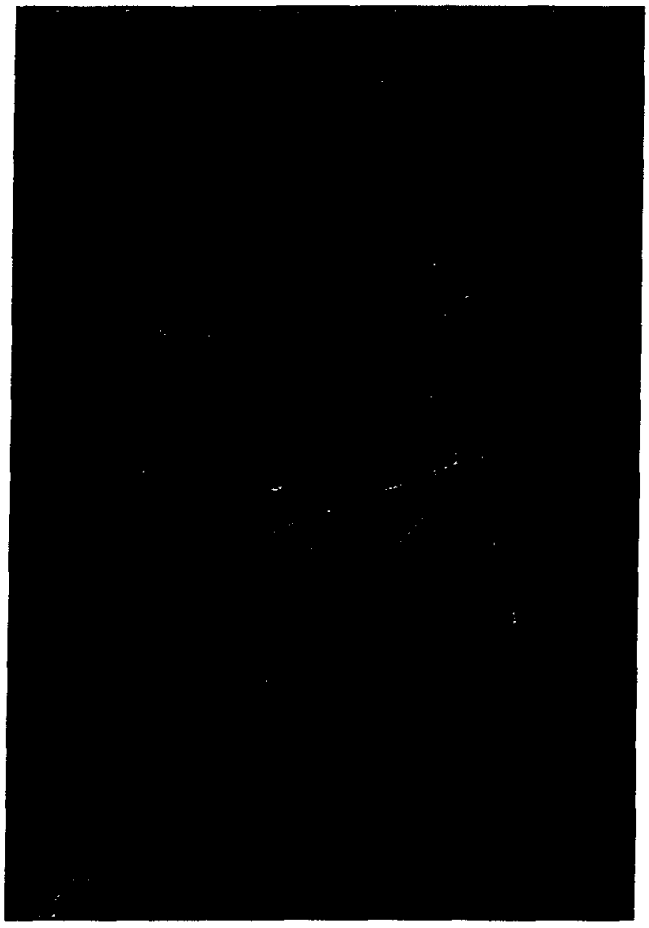
ANIMAL STUDIES

Authors: Smith, W.E., et al (25) Pub. 1979
Test Animals: Male LUG:LAK hamsters, injected at 2 months of age.
Test Type: Intrapleural injection
Protocol: Single intrapleural injection of two dosages (10 and 25 mg). The sample was suspended in saline and sterilized by autoclave. The occurrence of tumors (unspecified) was noted at necropsies for a starting group of 50 animals per dose. After short-term sacrifice of some animals and the loss of others through acute enteritis, the occurrence of tumors was noted in nonsurvivors up to 600 days.
Findings: Three tumors out of 41 animals were found at the 10 mg dose, and 12 out of 28 animals were found at the 25 mg dose.

OVERALL CONCLUSION: **A highly fibrous, possibly asbestiform tremolite (or byssollite) produced pleural tumors.**

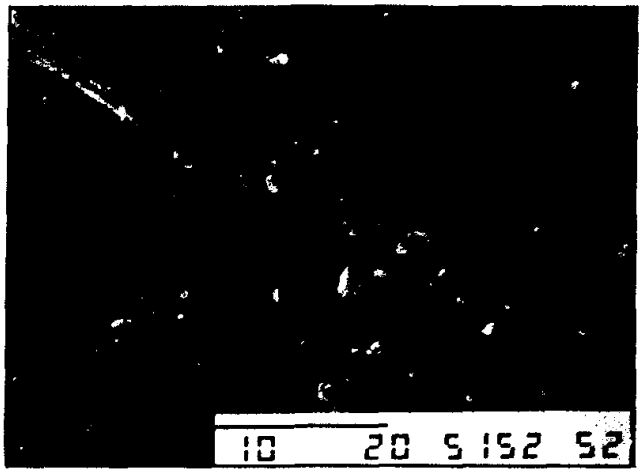
Nonasbestiform Tremolite with Asbestiform Subpopulation — Animal Study

Light Microscopy: 320 X



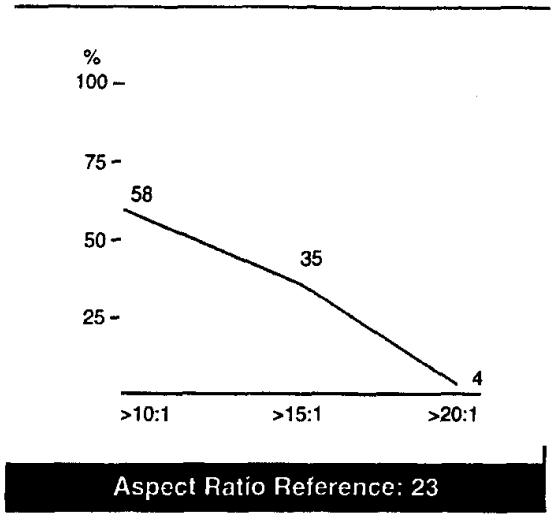
SEM: 1800 X

BULK MATERIAL

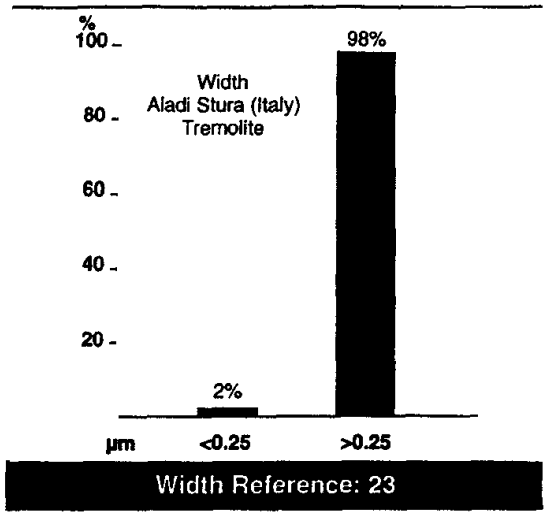


SAMPLE: The sample "consisted of large bundles of very long (often >5cm) needle-like fibers which were flexible and very elastic but quite brittle." "The tremolite from Italy contained mostly cleavage fragments, but some very long, thin fibers were observed." "The overall impression gained from dense SEM preparations, as shown in this paper, is that the Italian tremolite specimen did contain a certain amount of what observers would consider asbestiform fibers" (20).

Minerals have been characterized and verified as tremolite by x-ray diffractometry, optical microscopy, scanning electron microscopy and energy dispersive x-ray spectroscopy.



Aspect Ratio Reference: 23



Width Reference: 23

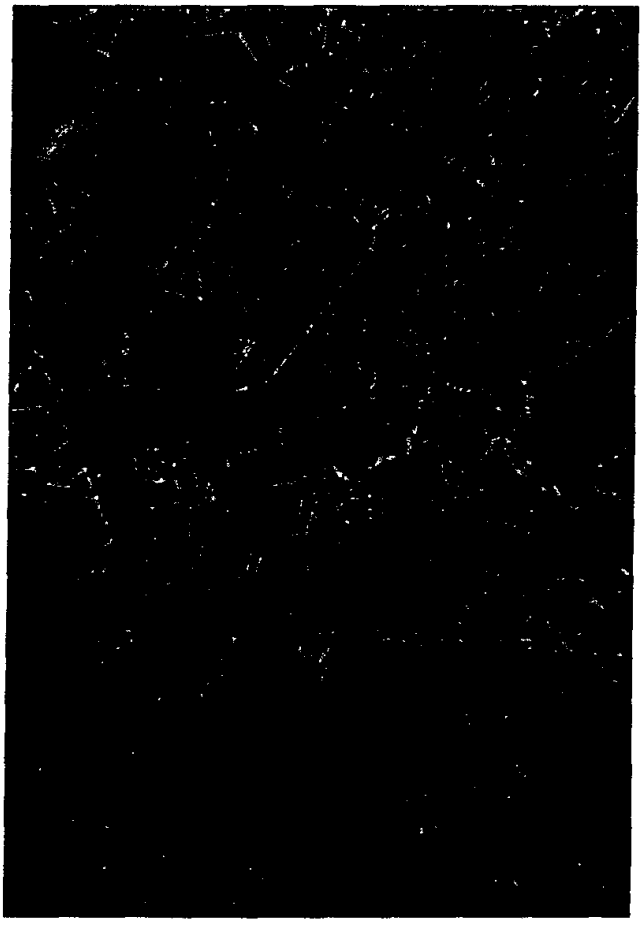
ANIMAL STUDIES

Authors: Davis, J.M.G., Addison, J. (20) Pub. 1991
Test Animals: AF/Han strain rats
Test Type: Peritoneal injection
Protocol: Fractions of this sample were obtained by generating an airborne dust cloud in an experimental chamber (Timbrell dust dispensers) with fine fractions collected using a vertical elutriator. A single 10 mg dose was injected into the peritoneal cavities of the animals. All animals lived out of their full life span or were killed when moribund.
Findings: 24 mesothelioma deaths out of 36 animals were observed with a median survival time of 755 days (contrasted to much shorter survival time for samples containing many tremolite asbestos fibers).

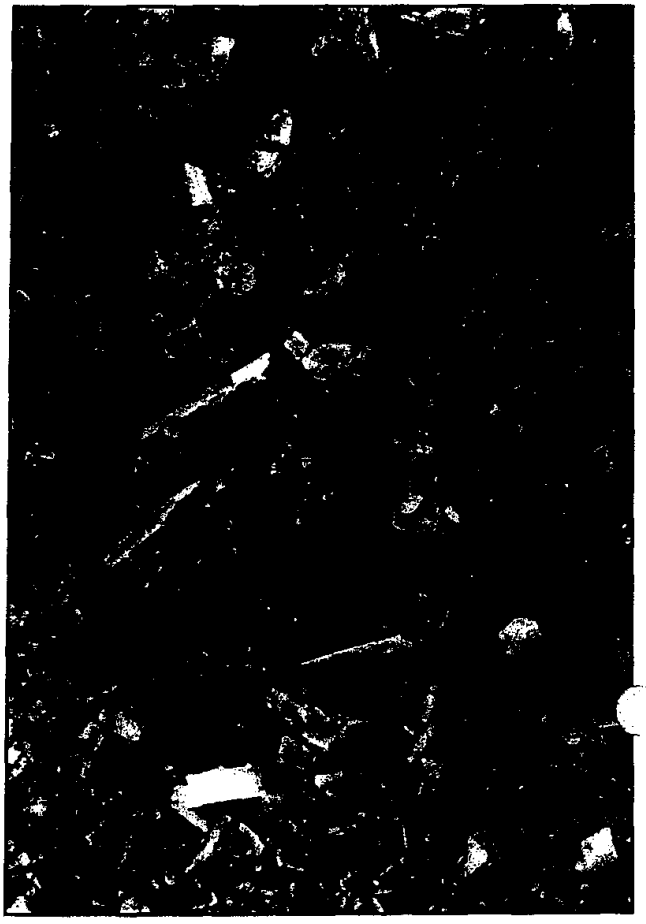
OVERALL CONCLUSION: **Sample suggests the asbestiform subpopulation influenced late tumor development.**

Nonasbestiform Grunerite — Human Mortality Study

Light Microscopy: 320 X



SEM: 1200 X



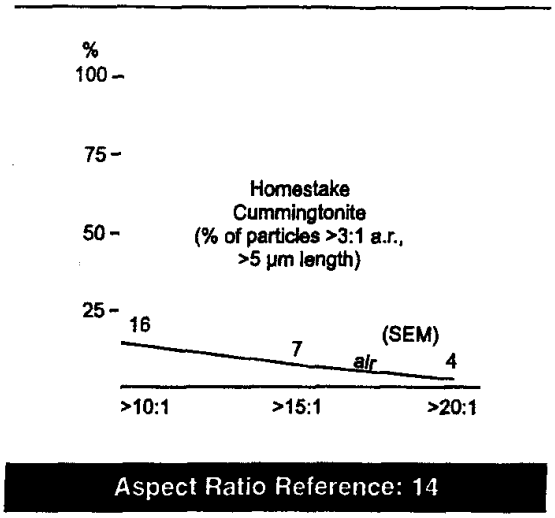
ORE: The ore is a cummingtonite-grunerite, quartz deposit mined for its gold in Lead, S. Dakota (33).

ADDITIONAL MINERAL PARTICLE DATA:

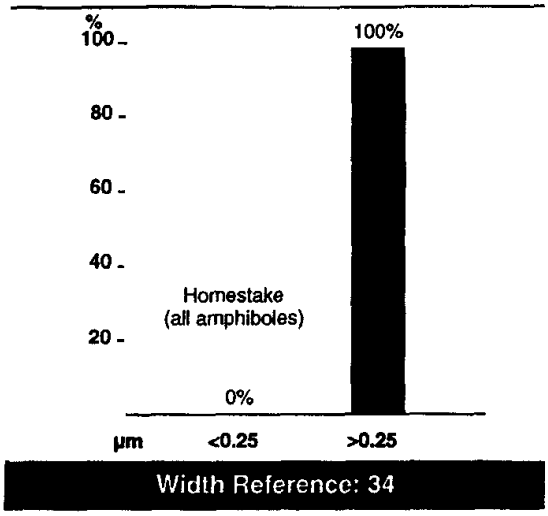
266 Fibers examined with aspect ratio of > 2:1 (air)

Minimum Width =	0.3 µm	Minimum Length =	0.9 µm
Mean Width =	1.1µm	Mean Length =	4.6 µm
Maximum Width =	4.8 µm	Maximum Length =	17.5 µm

"Eighty-four percent of the airborne fibers were identified as amphiboles." "Sixty-nine percent of the amphiboles were characterized as CG, 15% as tremolite-actinolite, with the remaining 16% identified as fibrous hornblende minerals" (33). Note: tremolite-actinolite is reported as an atypical heterogeneous occurrence.



Aspect Ratio Reference: 14



Width Reference: 34

HEALTH STUDIES

Authors: McDonald, J.C., et al (35) Pub. 1978
Cohort: 1,321 men, worked > 21 years (in Co. Veteran's Assoc.)
Vital Status Cut Off: 1973
SMR (respiratory cancer): 103
Conclusion: "There was no convincing evidence of an increase in respiratory cancer." Relative to a high mortality from silicosis and respiratory cancer - "It is difficult to believe that deaths with so wide a distribution could systematically have blocked the appearance of respiratory cancer."

Authors: Brown, D.P., et al (33) Pub. 1986
Cohort: 3,328 men, > 1 year experience underground work between 1940 and 1965
Vital Status Cut Off: June 1, 1977
SMR (respiratory cancer): 100
Conclusion: "No association as measured by length of employment underground, by dose (total dust x time), or by latency was apparent with lung cancer mortality.

Authors: Steenland, K. et al (67) Pub. 1995
Cohort: 3,328 men, >1 year experience underground between 1940 and 1965
Vital Status Cut Off: Dec. 12, 1990
SMR (respiratory cancer): 115 (CI 94-136)
Conclusion: "Neither exposure to nonasbestiform amphiboles nor silica was likely to be responsible for the observed excess of lung cancer, at least not in a way related to quantitative exposure to dust." "There was only one death from asbestosis in this cohort -- it would therefore appear that the nonasbestiform fibers in this mine did not cause any marked excess of either asbestosis or lung cancer."

OVERALL CONCLUSION: **Nonasbestiform amphibole exposure in this mining operation is not linked to excess lung cancer or mesotheliomas.**

EXPOSURE EXHIBIT L — *EAST MESABI RANGE TACONITE*

Nonasbestiform Grunerite — Human Mortality Study

Light Microscopy: 320 X

SEM: 1200 X

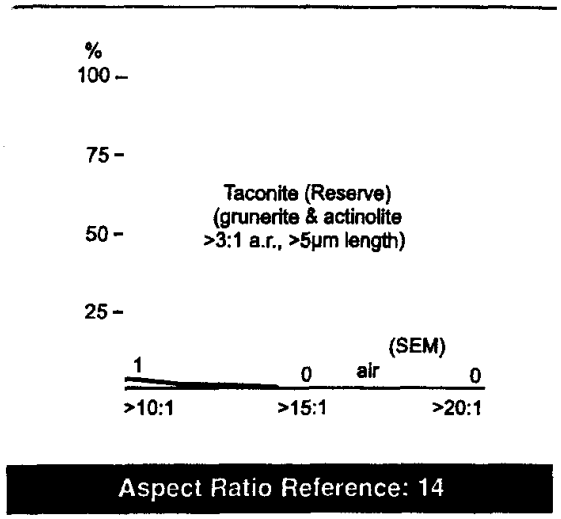
ORE: Minnesota taconite contains cummingtonite-grunerite, actinolite and hornblende amphiboles. Trace amounts of riebeckite also occur (36).

ADDITIONAL MINERAL PARTICLE DATA:

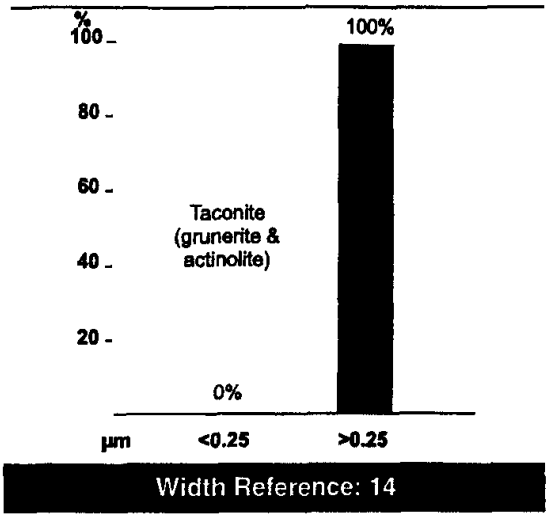
464 Fibers characterized with aspect ratio of > 2:1 (air)

Minimum Width =	0.25 µm	Minimum Length =	1.0 µm
Mean Width =	1.2 µm	Mean Length =	5.5 µm
Maximum Width =	5.0 µm	Maximum Length =	32.4 µm

"Zoltai and Stout (1976) in a report prepared for the Minnesota Pollution Control Agency, concluded that the cleavage fragments of cummingtonite-grunerite found in the Peter Mitchell Pit (Reserve Mining) should not be referred to as asbestiform" (37). "The fibers of taconite are short in length, the vast majority being less than 10 µm" (14).



Aspect Ratio Reference: 14



Width Reference: 14

HEALTH STUDIES

Authors: Higgins, I.T.T., et al (38) Pub. 1983 (Reserve Mining Co.)
Cohort: 5,751 men, worked > 1 year, 1952 to 1976
Vital Status Cut Off: July 1, 1976
SMR (respiratory cancer): 84 (full cohort), 102 (> 15 years latency)
Conclusion: "This study does not suggest any increase in cancer mortality from taconite exposure."

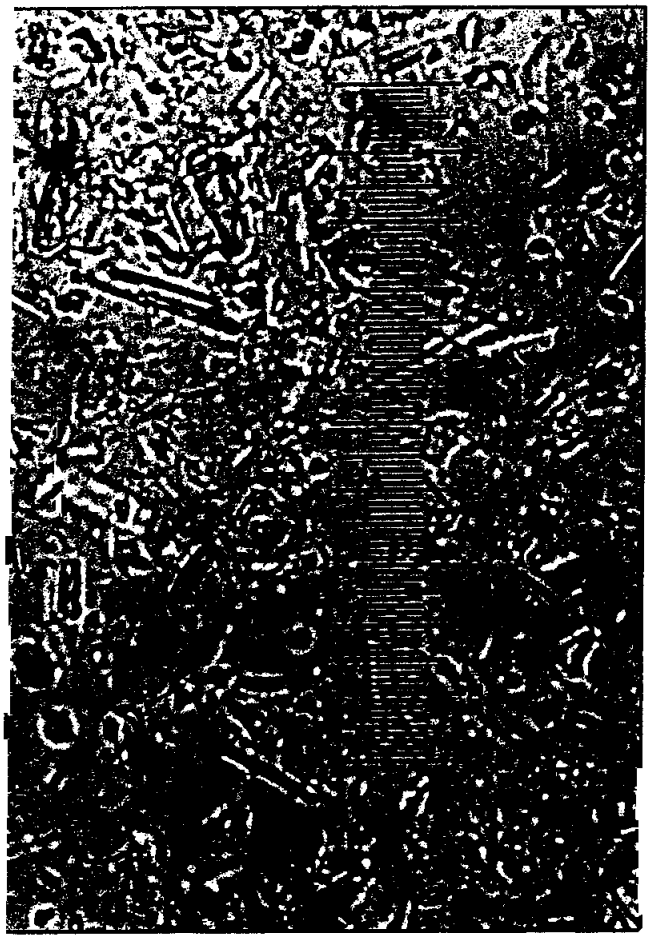
Authors: Cooper, W.C., et al (39) Pub. 1988 (Erie & Minntac Miners)
Cohort: 3,444, worked > 3 months 1947 to January 1, 1959
Vital Status Cut Off: 1983
SMR (respiratory cancer): 61 (full cohort), 57 (> 20 years latency)
Conclusion: "Respiratory tract cancer deaths were 39% fewer than expected (U.S. comparison) and 15% fewer than expected for Minnesota white men. Even when analysis was limited to deaths 20 or more years after first exposure, which provided ample opportunity for the leading edge of any excess in latent tumors to appear, there was no excess.

Authors: Cooper, W. C. et al (68) Pub. 1992 (Erie & Minntac Miners)
Cohort: 3,341 men, worked >3 months 1947 to Jan. 1, 1959
Vital Status Cut Off: Dec. 1988 (update - minimum 30 yr. observation period)
SMR (respiratory cancer): 67 (full cohort)
Conclusion: "no evidence to support any association between exposure to quartz or elongated cleavage fragments of amphibole with lung cancer, nonmalignant respiratory disease or any other specific disease."

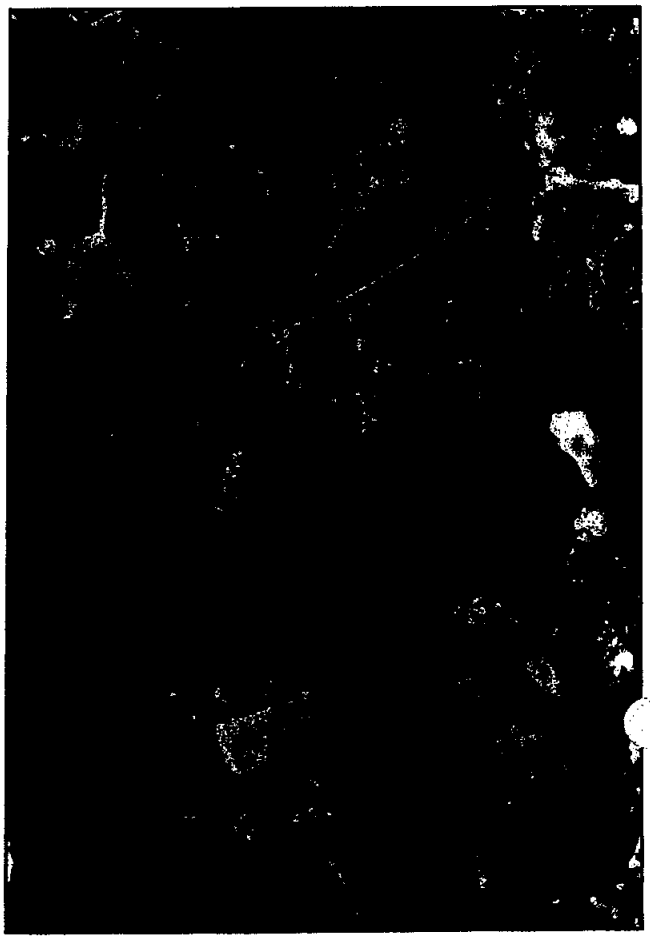
OVERALL CONCLUSION: **Nonasbestiform amphibole exposure in this mining operation is not linked to excess lung cancer.**

Nonasbestiform Tremolite — Human Mortality Studies and Animal Studies

Light Microscopy: 320 X

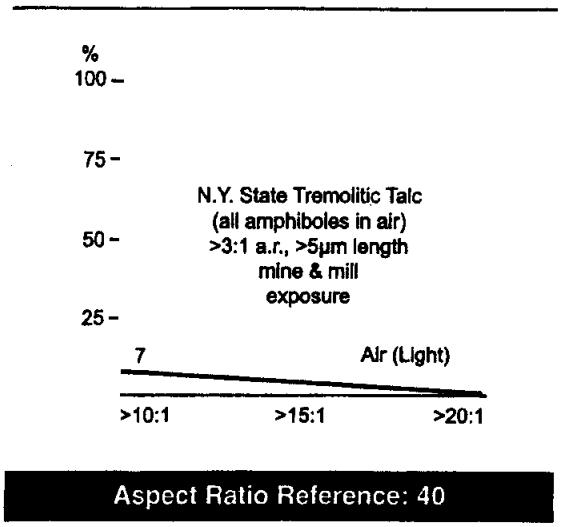


SEM: 1250 X

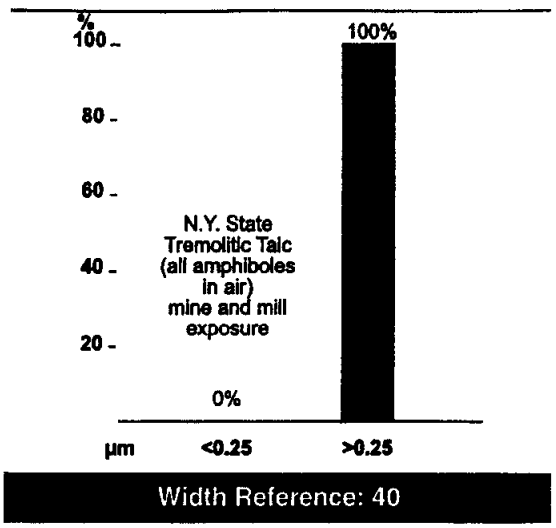


ORE: As mined and milled at the R. T. Vanderbilt Co., Gouvemeur N.Y. mine: mainly talc (20-40%), and tremolite (40-60%) with minor antigorite and anthophyllite. Quartz trace, if detected at all (40).

Also contains minor but observable rod-like mixed talc/amphibole and ribbon-like talc fiber. (69).



Aspect Ratio Reference: 40



Width Reference: 40

ADDITIONAL MINERAL PARTICLE DATA:

R. T. Vanderbilt Mine: NIOSH reported upwards of 70% amphibole asbestos based upon % of all 3:1 aspect ratio or greater particles in air (41). However, the mining company states that **all** of the tremolite and anthophyllite in its talc products appear only in the nonasbestiform habit (42,43). Varying in concentration from one grade to another, fibers of the mineral talc and to a much smaller extent "transitional" particles (talc evolving from anthophyllite) may also be found in this ore deposit. Some of these fibers do exhibit gross morphological characteristics consistent with an asbestiform habit. Such fibers, however, are rare and possess certain physical-chemical properties very different from amphibole asbestos (i.e. harshness, surface properties, etc.). Once fibrous talc is recognized in the analysis, the absence of asbestos in this material is consistently confirmed (40,44-49).

Stanton-Tremolitic Talc Samples 6 and 7: These talcs were positively identified as N.Y. State tremolitic talcs (50), and described as "refined raw materials for commercial products" (27). Sample 6 contained some very elongated particles which are likely to be talc fibers (see discussion above). These fibers did satisfy Stanton's critical dimension range (< 0.25 μm width, > 8 μm length). Sample 7 was reported as containing no particles in this dimensional range but is likely to be another fraction of the same sample.

Smith-Tremolitic Talc FD-14: This sample was supplied by the R. T. Vanderbilt Company and represents a high fiber product grade known as IT-3X (as sold). Analysis reported 50% tremolite, 10% antigorite, 35% talc (of which 25% was fibrous), 2-5% chlorite. Median particle length was 8.5 μm. Diameters (2,000X): < 1 μm = 20%, 1-2 μm = 36%, 2-4 μm = 32%, 4-6 μm = 8%, 6-8 μm = 2%, 10 μm = 2% (51). Tremolite varied considerably in their size lengths, ranging from 1 μm to 40-50 μm. "Talc fiber is abundant in the specimens, occurring as finely fibrous material with high aspect ratio. The talc fibers are also mineral mixtures, structurally talc and a magnesium amphibole. These minerals are also mixtures compositionally. The tremolite contained within the talc occurs as cleavage fragments and is not asbestiform on any level of examination" (45). (Reference includes specific analysis of International Talc-3X product.) In this animal study, this sample was used without comminution or separation.

HEALTH STUDIES (R. T. Vanderbilt Company, Inc.)

Authors: Brown, D.P., Wagoner, J.K., (NIOSH) (41) Pub. 1980
Cohort: 398 men, any work period between 1947-1959
Vital Status Cut Off: 1979 **SMR (resp. cancer):** 27
Conclusion: "Exposures to asbestiform tremolite and anthophyllite stand out as the prime suspect etiologic factors associated with the observed increase in bronchogenic cancer. . ." No confirmed mesotheliomas.
Critique: Amphibole asbestos is not involved. Excess lung cancer was not reasonably shown to be casually associated with the dust exposure (52-58).

Authors: Stille, W.T., Tabershaw, I.R. (59) Pub. 1982
Cohort: 708 men, any work period between 1947-1977
Vital Status Cut Off: 1978 **SMR (resp. cancer):** 157
Conclusion: "Elevated mortalities but no significant increases in number of deaths from lung cancer. . ." ". . .workers with exposures in other jobs prior to work at the TMX were found to have excessive mortality from lung cancer. . ."
Critique: Inadequate latency analysis, small cohort and missing data (i.e., smoking) (60).

Authors: Lamm, S.H., et al (61) Pub. 1988
Cohort: 705, worked any time between 1947-1977
Vital Status Cut Off: 1978 **SMR (resp. cancer):** 220
Conclusion: "This increase in lung cancer mortality. . .has been shown to be concentrated in short term employees (in contrast with nonmalignant respiratory disease). This increase. . . is most likely due to risk acquired elsewhere, such as prior employments, or to differences in smoking experience or other behavioral characteristics." "The risk did not appear to be associated with either the magnitude or the duration of exposure of GTC and was not different from that of workers at talc plants where ores did not contain tremolite or anthophyllite."
Critique: "The findings of these analyses. . . are based on assumptions, small numbers and short latency" (62).

Authors: Brown, D. P. et al (NIOSH) (70) Pub. 1990. Health Hazard Evaluation Report: Update of original NIOSH 1980 study
Cohort: 710, worked any time between 1947-1978
Vital Status Cut Off: 1983 **SMR (resp. cancer):** 207
Conclusion: "Workplace exposures at GTC are, in part, associated with these excesses in mortality. Possible confounding factors, such as cigarette smoking and other occupational exposures from employment elsewhere, may have contributed to these risks as well."
Critique: "When stratified by smoking, the odds ratios decreased with tenure and the trend analysis were significant. In short, the analysis showed a strong association between lung cancer and cigarette smoking, and there appeared to be an inverse relationship between exposure and the development of lung cancer." (71).

Authors: Gamble, J., et al (71) Pub. 1993
Cohort: Case control applied to above NIOSH Cohort **SMR (resp. cancer):** 207
Conclusion: "When stratified by smoking station, risk of lung cancer decreased with talc tenure and remained negative when excluding cases with <20 years latency and short-term workers. These data suggest that non-talc exposures are not confounding risk factors (for lung cancer) while smoking is, and that temporal and exposure-response relationships are consistent with a smoking etiology but not an occupational etiology for lung cancer."
Critique: No dust data and disagreement over whether the elevated smoking rates would or would not account for all the excess.

Authors: Honda, Y. et al (73) Pub. 2002
Cohort: 818 men, worked any time between 1947-1998 (Retrospective Mortality study update with exposure estimation study)
Vital Status Cut Off: January 1, 1990 **SMR (resp. cancer):** 254

Conclusion: "The results of this study are similar to those of earlier investigations. The cohort giving rise to the lung cancer was seen among subjects unexposed to GTC talc. These features suggest that some of the apparent increase is due to exposure to tobacco smoke. Mill workers and mine workers had similar estimated cumulative dust exposures, yet the excess of lung cancer was considerably stronger among miners than among millers. This indicates that GTC talc dust, per se, did not produce the excess. Most important, the presence of an inverse relationship between estimated cumulative exposure and lung cancer is inconsistent with the hypothesis that GTC talc dust is a carcinogen. The results of experimental animal studies also do not provide any support for this hypothesis."

ANIMAL STUDIES

Authors: Stanton, M.F., et al (27) Pub. 1981
Test Animals: 20-week-old outbred female Osborne-Mendal rats
Test Type: Pleural implantation
Protocol: A standard 40 mg dose of each sample was uniformly dispersed in hardened gelatin and applied by open thoracotomy directly to the left pleural surface. The animals (30-90 for each experiment) were followed for 2 years, at which time all surviving animals were sacrificed and the tissues examined for pleural sarcomas.
Findings: Exposure to these tremolitic talc samples resulted in no incidence of tumors. Similarly tested tremolite asbestos reflected a high tumor rate (see Exposure Exhibit G).

Authors: Smith, W. E., et al (25) Pub. 1979
Test Animals: Male LUG:LAK hamsters, injected at 2 months of age
Test Type: Intrapleural injection
Protocol: Single intrapleural injection of two dosages (10 and 25 mg). The sample was suspended in saline and sterilized by autoclave. The occurrence of tumors (unspecified) was noted at necropsies for a starting group of 50 animals per dose. After short term sacrifice of some animals and the loss of others through acute enteritis, the occurrence of tumors was noted in nonsurvivors up to 600 days.
Findings: No tumor development was noted. In contrast, tremolite asbestos similarly tested did produce tumors (see Exposure Exhibit F).

CELL STUDIES

Authors: Wylie, A. G., Mossman, B. T. et al (72) Pub. 1997
Study: In vivo cytotoxicity and proliferative potential in HTE & RPM cells contrasting asbestos fibers to similar dose talc and transitional fibers (concentrate) from RTV talc.
Conclusion: "Our experiments also show that fibrous talc does not cause proliferation of HTE cells or cytotoxicity equivalent to asbestos in either cell type despite the fact that talc samples contain durable mineral fibers with dimensions similar to asbestos. These results are consistent with the findings of Stanton, et al (1981) who found no significant increases in pleural sarcomas in rats after implantation of materials containing fibrous talc."

OVERALL CONCLUSION: **Human Studies - A definite link between nonasbestiform tremolite and respiratory cancer in the R. T. Vanderbilt Company talc mining population has not been demonstrated.**

Animal Studies - N. Y. State tremolitic talc containing a high nonasbestiform tremolite content produced no carcinogenic response in rats or hamsters.

EXPOSURE EXHIBIT N

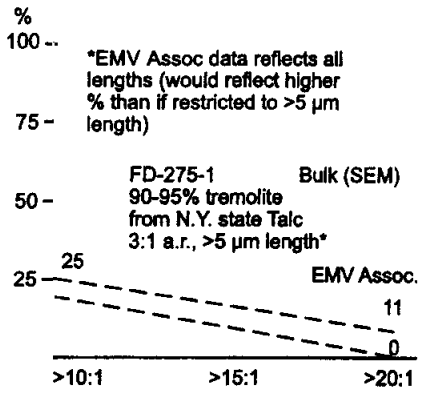
SMITH-TREMOLITE FD-275-1 AND MCCONNELL TREMOLITE 275

Nonasbestiform Tremolite — Animal Studies

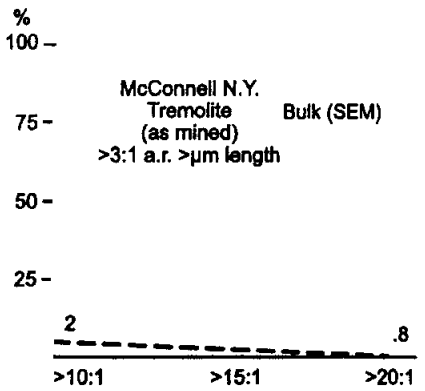
Light Microscopy: 320 X

SEM: 1250 X

SAMPLE: Both FD-275-1 and 275 originated from N.Y. State tremolitic talc ore. Both samples represent tremolite concentrates from this ore.



Aspect Ratio Reference: 23



Aspect Reference: 23

ADDITIONAL MINERAL PARTICLE DATA:
Tremolite 275 was selected from N.Y. tremolitic talc ore from an area rich in tremolite. This ore was provided to the Bureau of Mines (BOM) for mineral and elemental particle size characterization as well as use in an animal feeding study by Dr. E. McConnell (sample contained approximately 70% tremolite with the remainder talc and antigorite). Also, an aliquot of this sample was further processed to obtain a higher tremolite concentrate for use in another animal study by Dr. William Smith (approximately 95% tremolite).

The processing of FD-275-1 involved crushing, milling, separation via sedimentation and filtering to obtain only the respirable fraction. Particle size characterization of FD-275-1 was undertaken by Dr. Smith (via EMV Assoc. Inc.), and by the BOM.

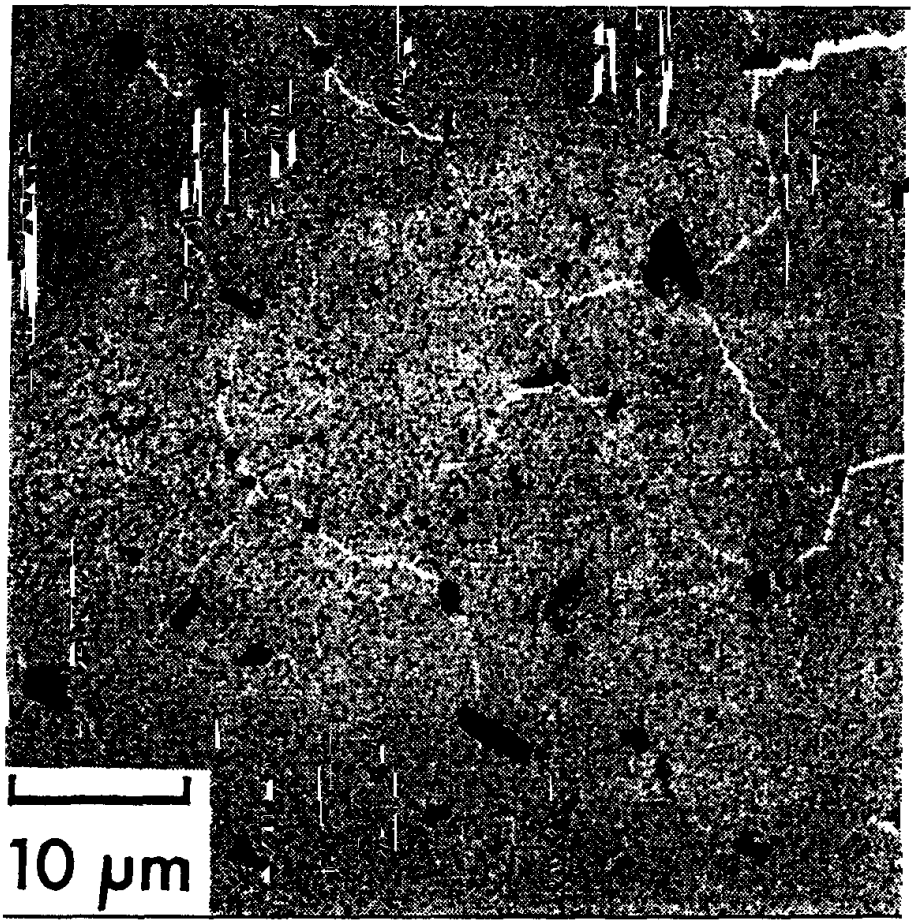
For FD-275-1, no particles with a width < 1 µm and length of > 10 µm were observed (200 particles via SEM). For FD-275 (McConnell tremolite), a mean width of 3.4 µm for particles > 6 µm in length was recorded (for amosite similarly sized mean width = 0.4 µm).

ANIMAL STUDIES
Authors: Smith, W.E., et al (25) Pub. 1979
Test Animals: Male LUG:LAK Hamsters **Test Type:** Intrapleural injection
Protocol: Single intrapleural injection of two dosages (10 and 25 mg). The occurrence of tumors (unspecified) was noted at necropsies for a starting group of 50 animals per dose. After short term sacrifice of some animals and the loss of others through acute enteritis, the occurrence of tumors was noted in nonsurvivors up to 600 days.
Findings: No tumor development was noted. In contrast, tremolite asbestos similarly tested did produce tumors (see Exposure Exhibit F).

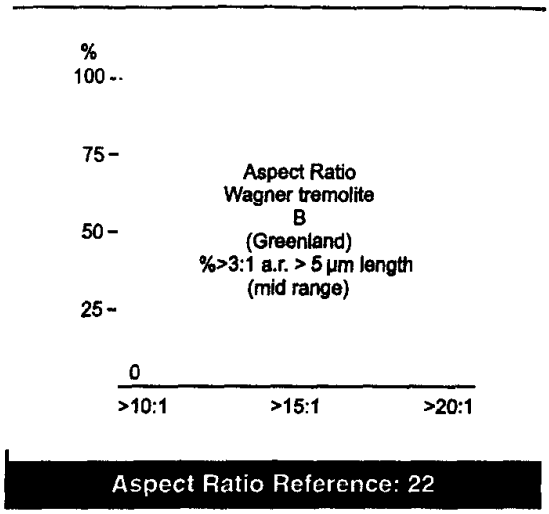
Authors: McConnell, E.E., et al (64) Pub. 1983
Test Animals: Male and female Fischer 344 rats **Test Type:** Ingestion
Protocol: Nonasbestiform tremolite and amosite were administered alone and in combination at a concentration of 1% in the daily diet of rats. Rats were sacrificed when exhibiting specified symptoms, or when less than 10% of the test group survived. Group size varied from 100 to 250 animals.
Findings: No toxic or neoplastic lesions were observed in the target organs - gastrointestinal tract, or mesothelioma for either the tremolite or the amosite.

OVERALL CONCLUSION: **A concentrate of N.Y. State tremolite nonasbestiform produced no pleural tumors in hamsters and no gastrointestinal tract neoplastic lesions in rats.**

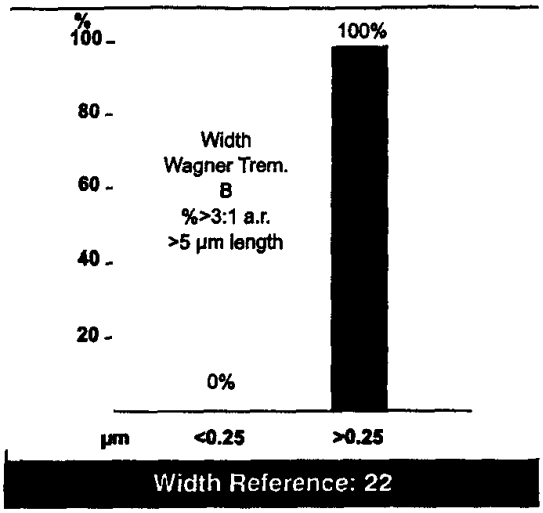
Nonasbestiform Tremolite — Animal Study



SAMPLE: Prepared from a rock specimen from Greenland. Referenced as tremolite "B" (22).



Aspect Ratio Reference: 22



Width Reference: 22

ADDITIONAL MINERAL PARTICLE DATA:

100% of particles > 5 µm have diameters > 1.0 µm
100% of particles are less than 10 µm long
100% of particles > 5 µm length have aspect ratios < 10:1 (22)

ANIMAL STUDIES

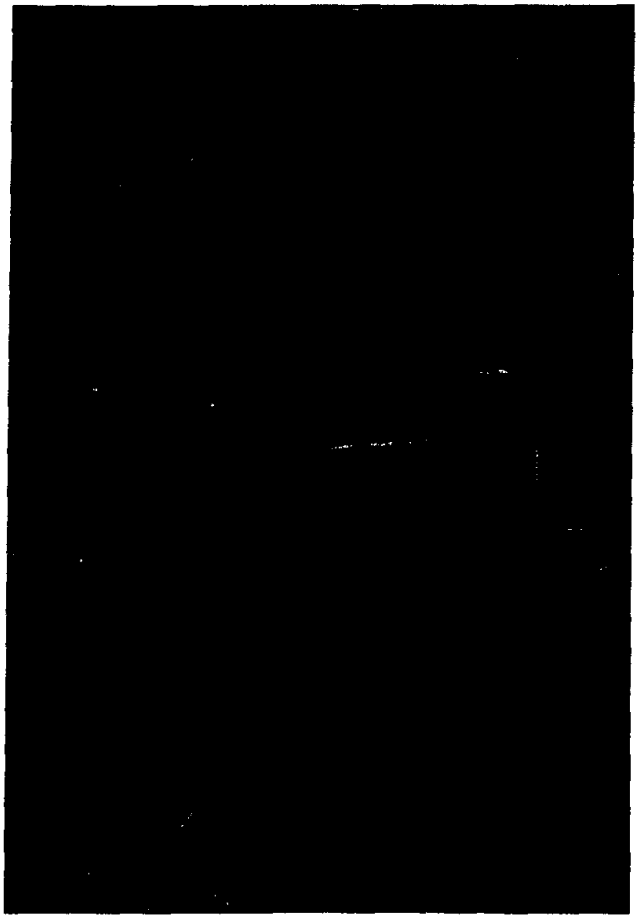
Authors: Wagner, J.C., et al (22) Pub. 1982
Test Animals: Sprague-Dawley rats 6-10 weeks old when injected
Test Type: Pleural injection
Protocol: A single 20 mg injection into the right pleural cavity of 48 rats was applied. "The sample was prepared by milling in a small agate mill and ultrasonic dispersion, large particles being removed by sedimentation in water." The sample was sterilized by autoclave and introduced in saline solution. All animals were allowed to live out their lives or necropsied when moribund for tumors (unspecified-reported as "mesotheliomas").
Findings: No tumors were noted in 48 rats. One sample of tremolite asbestos was tested under the same protocol (see Exposure Exhibit C).

OVERALL CONCLUSION: **Nonasbestiform tremolite produced no tumors in the test animals.**

EXPOSURE EXHIBIT P *ADDISON/DAVIS-TREMOLITE (Dornie)*

Nonasbestiform Tremolite — Animal Study

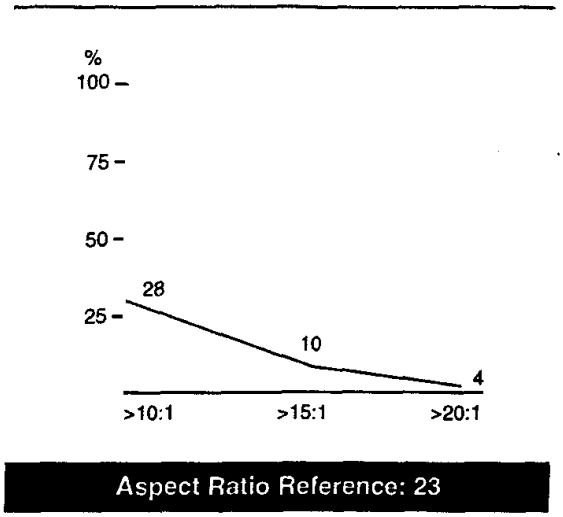
Light Microscopy: 320 X



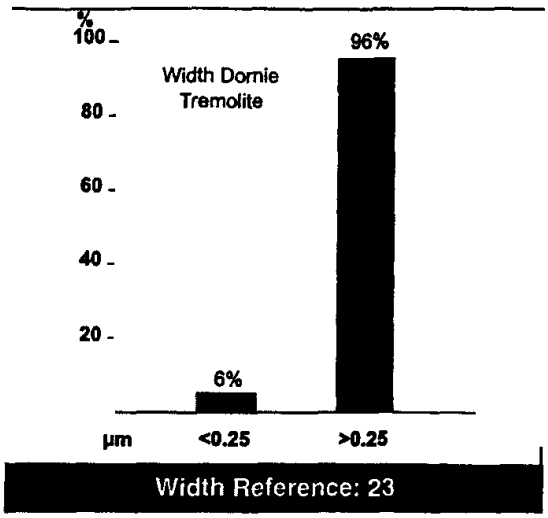
SEM: 190 X

SAMPLE: Like the tremolite from Italy (see exhibit J), this sample "contains mostly cleavage fragments, but some very long, thin fibers were also observed." There are more fibers longer than 8 µm in this sample than in the Italian sample, but most were >1 µm in diameter. A small amphibole asbestiform subpopulation may also exist in this sample as it does in the Italian sample (though this is less clear). "The material contains several populations of varying habits of a member of the tremolite-actinolite solid solution series. (65). Both this sample and the Italian sample are not typical of tremolite nonasbestiform cleavage fragment populations. Both exhibit the presence of bysollite in the samples.

Minerals were characterized and verified as a tremolite by x-ray diffractometry, optical microscopy, scanning electron microscopy and energy dispersive x-ray spectroscopy.



Aspect Ratio Reference: 23



Width Reference: 23

ANIMAL STUDIES

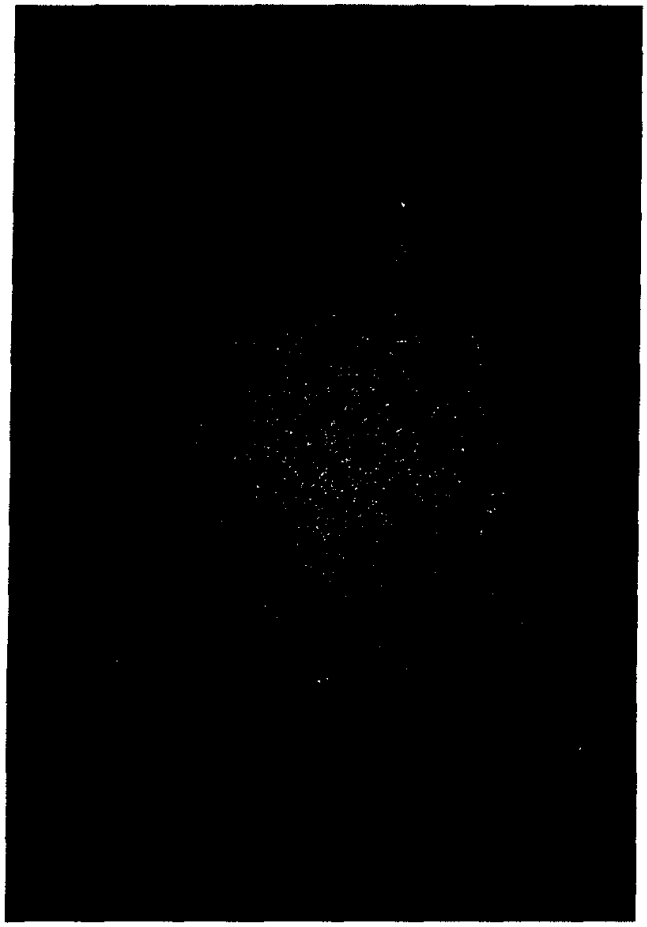
Authors: Davis, J.M.G., Addison, J. (20) Pub. 1991
Test Animals: AF/Han strain rats
Test Type: Peritoneal injection
Protocol: Fractions of this sample were obtained by generating an airborne dust cloud in an experimental chamber (Timbrell dust dispensers) with fine fractions collected using a vertical elutriator. A single 10 mg dose was injected into the peritoneal cavities of the animals. All animals lived out of their full life span or were killed when moribund.
Findings: 4 mesothelioma deaths out of 33 animals were observed with no median survival time published (too few tumors for median survival times to be calculated). It is important to note - as stated in the study - "The intraperitoneal injection test is extremely sensitive, and it is usually considered that, with a 10 mg dose, any dust that produced tumors in fewer than 10% of the experimental group is unlikely to show evidence of carcinogenicity following administration by the more natural route of inhalation - the material from Dornie is probably to be considered harmless to human beings."

OVERALL CONCLUSION: **This predominantly nonasbestiform tremolite produced no significant carcinogenic response in the test animals and is likely harmless to humans.**

EXPOSURE EXHIBIT Q *ADDISON/DAVIS-TREMOLITE (Shinness)*

Nonasbestiform Tremolite — Animal Study

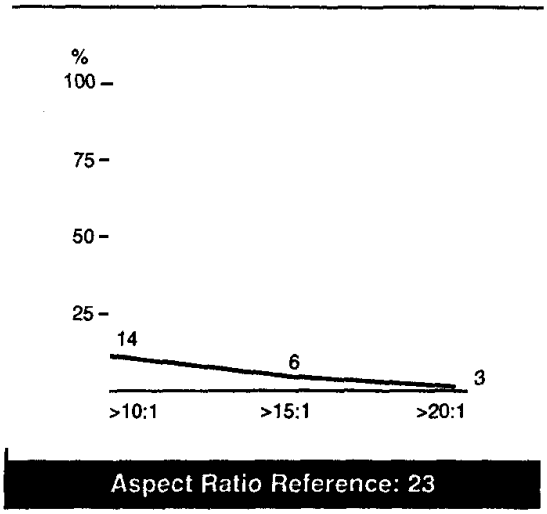
Light Microscopy: 45 X



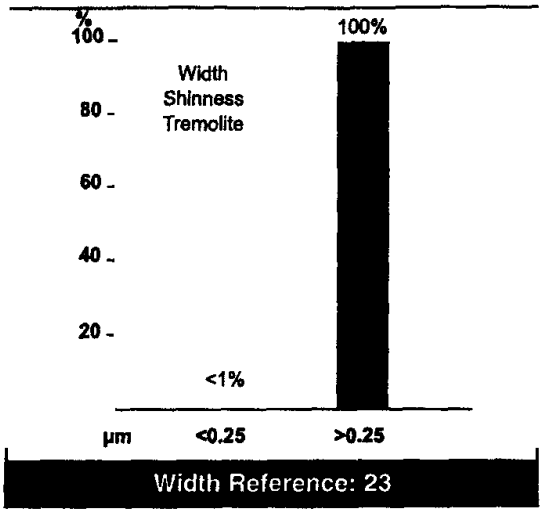
SEM: 1800 X

SAMPLE: "The Shinness tremolite dust was almost exclusively composed of cleavage fragments, only a small portion of which had an aspect ratio greater than 3:1."

Minerals were characterized and verified as tremolite by x-ray diffractometry, optical microscopy, scanning electron microscopy and energy dispersive x-ray spectroscopy.



Aspect Ratio Reference: 23



Width Reference: 23

ADDITIONAL MINERAL PARTICLE DATA:

"In the optical microscopy and SEM examinations, the asbestos tremolites were found to be typical of that form in displaying polyfilamentous fiber bundles, curved fibers, fibers with splayed ends, and long, thin, parallel-sided fibers. Most of the fibers showed straight extinction when observed with polarized light under crossed polarizers, indicating the presence of multiple twinning of the crystals." "Samples did contain some elongated fragments of tremolite with oblique extinction, stepped ends, and nonparallel sides indicating that they were cleavage fragments." (20)

ANIMAL STUDIES

Authors: Davis, J.M.G., Addison, J. (20) Pub. 1991
Test Animals: AF/Han strain rats
Test Type: Peritoneal injection
Protocol: Fractions of this sample were obtained by generating an airborne dust cloud in an experimental chamber (Timbrell dust dispensers) with fine fractions collected using a vertical elutriator. A single 10 mg dose was injected into the peritoneal cavities of the animals. All animals lived out of their full life span or were killed when moribund.
Findings: 2 mesothelioma deaths out of 36 animals were observed (well below background for test method). There were too few tumors for median survival times to be calculated. Authors state: "Human exposure to a material such as that obtained from Shinness Scotland, whether as a pure mineral dust or as a contaminant of other products, will almost certainly produce no hazard -"

OVERALL CONCLUSION: **This nonasbestiform tremolite produced no carcinogenic response in the test animals.**

Nonasbestiform Actinolite - Animal Study

No photograph available.

SAMPLE: Origin of sample unknown.

DIMENSIONAL DATA: Not provided by author.

ANIMAL STUDIES:
Authors: Pott, F. et al (66) Pub. 1974
Test Animals: Wistar rats
Test Type: Pertoneum injection.
Protocol: Assorted fibrous dust (chrysotile, anthophyllite asbestos, actinolite asbestos, wollastonite, glass fibers, gypsum, etc.) and granular dust (nonasbestiform actinolite, biotite, talc, etc.) were intraperitoneally injected (up to 12.5 mg/ml) into varying test groups of 40 rats at various dosages.
Findings: The "fibrous" dusts (with some exceptions such as gypsum, slag wool, and wollastonite), induced varying tumor development while the granular dusts reflected little to no tumors (nonasbestiform actinolite - no tumors). "Very low doses between 0.05 and 0.5 mg asbestos led to tumor incidences of about 20% to 80%."

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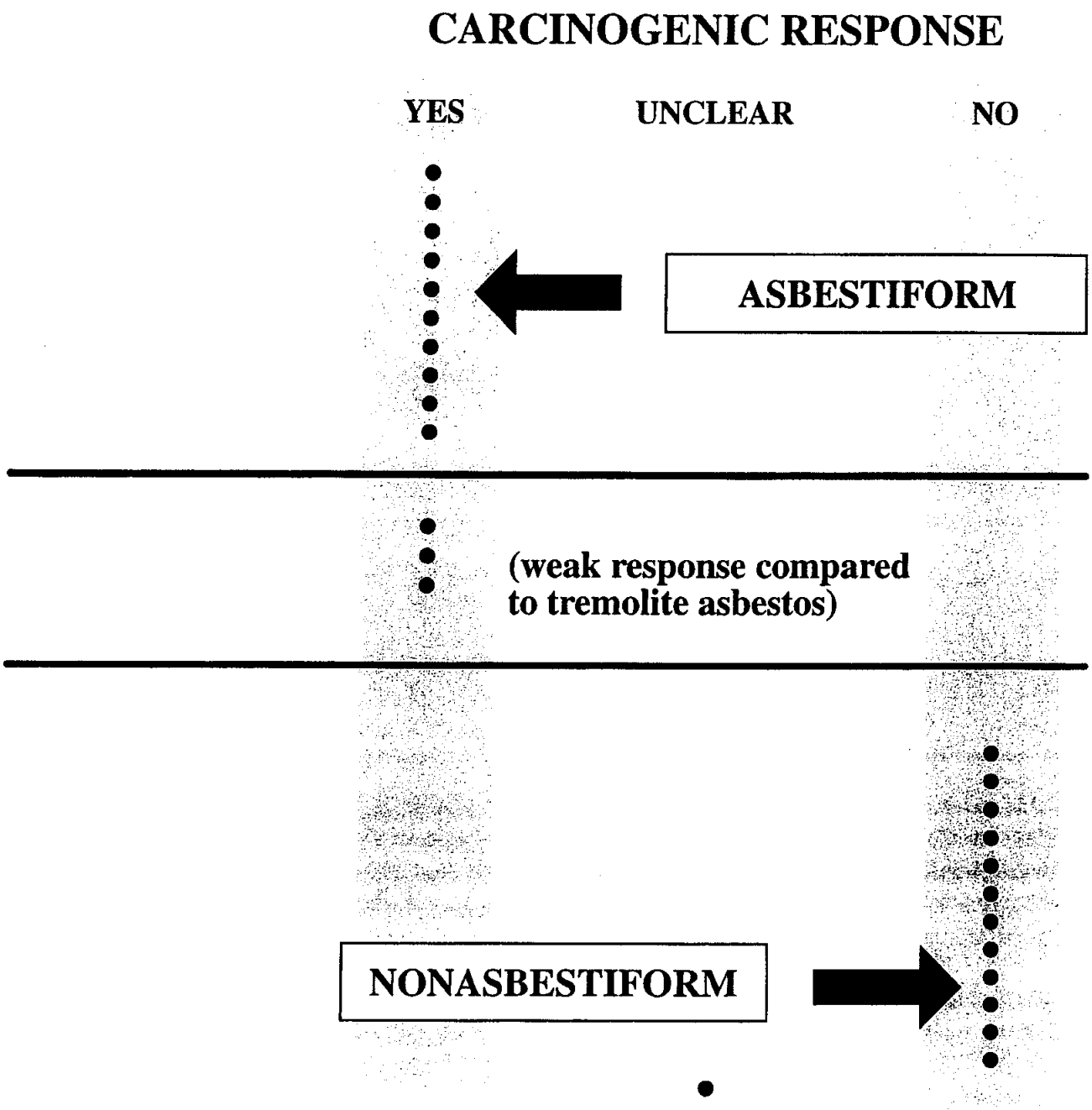
SUMMARY
MINERAL HABIT AND CARCINOGENICITY

CLEAR AMPHIBOLE ASBESTOS EXPOSURES (amphibole asbestos)	**Libby Vermiculite (H)** **Greek Tremolite (H)** **Smith FD-72 (A)** **Stanton Tremolite #1 (A)** **Stanton Tremolite #2 (A)** **Wagner Korean Tremolite (A)** **Davis Korean Tremolite (A)** **Addison/Davis Jamestown Tremolite (A)** **Addison/Davis Korean Tremolite (A)** **Addison/Davis Swansea Tremolite (A)**
PREDOMINANTLY ASBESTIFORM AND/OR HIGHLY FIBROUS	**Cook/Coffin-Ferroactinolite (asbestiform) (A)** **Smith FD-31 (unique Tremolite/Byssolite) (A)** **Addison/Davis Italian Tremolite (highly fibrous with asbestos subpopulation) (A)**
COMMON NONASBESTIFORM AMPHIBOLE EXPOSURES	**Homestake (C-G) (H)** **Mesabi Range-Taconite (C-G, trace Actinolite) (H)** **Smith FD-14 (Tremolitic Talc) (A)** **Smith FD-275 (conc. Tremolite) (A)** **McConnell Tremolite (conc. Tremolite) (A)** **Stanton Talc #6 (Tremolitic Talc) (A)** **Stanton Talc #7 (Tremolitic Talc) (A)** **Pott-Granular Actinolite (A)** **Wagner California Tremolite (A)** **Wagner Greenland Tremolite (A)** **Addison/Davis Dornie Tremolite (A)** **Addison/Davis Shinness Tremolite (A)** **N.Y. State Tremolitic Talc (neg. for animals) (H)**

(H) = Human Studies
(A) = Animal Studies
C-G = Cummingtonite-grunerite


CARCINOGENIC RESPONSE
YES
UNCLEAR
NO
ASBESTIFORM
(weak response compared
to tremolite asbestos)
NONASBESTIFORM

CONCLUSION

Difference Exists Mineralogically

AND

Biologically

In 1992, after many years of scientific review, the Occupational Safety and Health Administration (OSHA) specifically excluded the regulation of elongated nonasbestiform cleavage fragments from under the scope of their asbestos standard. OSHA's decision to recognize the key mineralogic and biologic distinctions reviewed in this pictorial presentation was instrumental in that decision.

Because this matter involves scientific issues ranging from geology, mineralogy and health, the authors believe it is important that these complex relationships be explained as simply as possible. This matter remains a source of confusion to many and the consequences of misunderstanding can be immense.

Sustaining confusion is an unfortunate array of overly broad asbestos analytical protocols and definitions now being applied in mixed dust environments. To address analytical ambiguities, appendix II is provided.

REFERENCES

1. Kuryvial, R. J., Wood, R. A., and Barrett, R. E. Identification and Assessment of Asbestos Emissions from Incidental Sources of Asbestos. Environmental Protection Agency Report, EPA-650/2-74-087 (1974).

2. United States Department of the Interior. Bureau of Mines. Analysis of the Cost Effectiveness of the OSHA Regulation of Nonasbestiform Amphiboles with Respect to Selected Sectors of the Domestic Minerals Industry. By Richard S. Gillett and Robert L. Virta. Washington, D.C., Bureau of Mines, September 22, 1989. p. 1-55.

3. Glossary of Geology, American Geological Institute, 801 pgs. G. M. McAfee and C. Wolf, Eds. (1974).

4. Snyder, J., Virta, R. L., and Segret, R. Evaluation of the Phase Contrast Microscopy Method for the Detection of Fibrous and other Elongated Mineral Particulates by Comparison with STEM Technique, American Industrial Hygiene Association Journal 48(5): 471-477 (1987).

5. Campbell, W. J., and Huggins, C. W., Wylie, A. G. Chemical and Physical Characterization of Amosite, Chrysotile, Crocidolite and Nonfibrous Tremolite for Oral Ingestion Studies by the National Institute of Environmental Health Sciences, U.S. Bureau of Mines Report of Investigation No. 8452, 1980, p. 48.

6. Gibbs, G. W., and Hwang, C. Y. Dimensions of Airborne Asbestos Fibers in Biological Effects of Mineral Fibers, Vol. 1, J.C. Wagner ed., IARC Scientific Publication No. 30, 1980, pp. 79-86, Lyon, France.

7. Pooley, F. D., and Clark, N. A. Comparison of Fiber Dimensions in Chrysotile, Crocidolite, and Amosite Particles from Sampling of Airborne Dust and from Post Mortem Lung Tissue Specimens, Biological Effects of Mineral Fibers, Vol. 1, J.C. Wagner ed., IARC Scientific Publication No. 30, 1980 pp. 79-86, Lyon France.

8. Wylie, A. G., and Schweitzer, P. The Effects of Sample Preparation and Measuring Techniques on the Shape and Shape Characterization of Mineral Particles, the case of Wollastonite. Environmental Research 1982, Vol. 27, p. 52-73.

9. Wylie, A. G. 1985, Collected on location by MSHA (Homestake Mining Company).

10. Eckert, J. Dimensions of Airborne Cummingtonite Particles from the Homestake Mine, Lead, South Dakota, unpublished senior thesis, Department of Geology, University of Maryland, 1981, p. 10.

11. Campbell, W. J., et al. Selected Silicate Minerals and Their Asbestiform Varieties, U.S. Bureau of Mines Information Circular No. 8751, 1977, p. 56.

12. Campbell, W. J., Steel, E. B., Virta, R. L., and Eisner, M. H. Relationship of Mineral Habit to Size Characteristics for Tremolite Cleavage Fragments and Fibers, U.S. Bureau of Mines Report of Investigation No. 8367, 1979, p. 18.

13. McDonald, J.C., McDonald, A. D., Armstrong, B., and Sebastien, P. Cohort Study of Mortality of Vermiculite Miners Exposed to Tremolite, British Journal of Industrial Medicine (1986), 43: 436-444.

14. Wylie, A. G. Relationship Between the Growth Habit of Asbestos and the Dimensions of Asbestos Fibers, Mining Engineering (November 1988), p. 1036-1040.

15. Amandus, H., Wheller, R., and Jankovic, J. Part II: The Morbidity and Mortality of Vermiculite Miners and Millers Exposed to Tremolite-Actinolite. Part I: Exposure Estimates. American Journal of Industrial Medicine 1987; 11:1-14.

16. Langer, A. M., Mackler, A. D., and Pooley, F. D. Environmental Health Perspectives (1974), Vol. 9, p. 63-80.

17. Langer, A. M., and Nolan, R. P. Letter to the R. T. Vanderbilt Company, Inc., March 12, 1990.

18. Langer, A. M., Nolan, R. P., Constantopoulis, S. H., and Moutsopoulis, H. M. Association of Metsovo Lung and Pleural Mesothelioma with exposure to Tremolite Containing Whitewash (1987), The Lancet I, April. p. 965-967.

19. Lee, R.J. Correspondence to Rick Renninger, National Stone Association, on the source of Korean tremolite asbestos samples used in J.M.G. Davis and Wagner animal studies, April 21, 1990.

20. Davis, J.M., Addison, J., McIntosh, C., Miller, M., Niven, K.: Variations in the Carcinogenicity of Tremolite Dust Samples of Differing Morphology; Annals of the New York Academy of Sciences Vol. 643 (1991) pp. 473-490

21. Davis, J. M. G., Addison, J., Bolton, R. E., Donaldson, K., Jones, A. D., and Miller, B. G. Inhalation Studies on the Effects of Tremolite and Brucite Dust: Carcinogenesis 1985; 6:667-674.

22. Wagner, J. C., and Berry, C. B. Mesotheliomas in Rats Following Inoculation with Asbestos. Br. J. Cancer 1969, 23:567 and Wagner, J. C. et al Biological Effects of Tremolite. British Journal of Cancer 1982: 45:352-360.

23. Lee, R. J. Correspondence to Rick Renninger, National Stone Association, relaying aspect ratio and width distribution data on the J. Addison and J.M.G. Davis tremolite samples, April 16, 1990.

24. EMV Associates, Inc. Consultant Report to R. T. Vanderbilt Company, Inc. on Particle Size Analysis of Tremolite Samples, September 1977.

25. Smith, William E., Hubert, D., Sobel, H., and Marquet, E. "Biologic Tests of Tremolite in Hamsters." Dusts and Disease, p. 335-339, (1979).

26. Harvey, A. M. Interoffice Memorandum - R. T. Vanderbilt Company, Inc. to Dr. C. S. Thompson - Subject: Tremolite Asbestos. February 11, 1976.

27. Stanton, M. F., Layard, M., Tegeris, A., Miller, E., May, M., Morgan, E., and Smith, A. Relation of Particle Dimension to Carcinogenicity in Amphibole Asbestoses and Other Fibrous Minerals. Journal of the National Cancer Institute 1981; 67:965-975.

28. Wylie, A. G., et al. Characterization of Mineral Population by Index Particle: Implication for the Stanton Hypothesis. Env. Res. 1985; 43:427-439.

29. Coffin, D. L., Palekar, L. D., and Cook, P. M. Tumorigenesis by a Ferroactinolite Mineral. Toxicology Letters, 13 (1982) 143-150.

30. Cook, P. M., Palekar, L. D., and Coffin, D. L. Interpretation of the Carcinogenicity of Amosite Asbestos and Ferroactinolite on the Basis of Retained Fiber Dose and Characteristics In Vivo. Toxicology Letters, 13 (1982) 151-158.

31. Leineweber, J. Correspondence to W. Smith with sample FD-31 (Johns-Manville Corp.) (1976).

32. Wylie, A. G. Letter to F. A. Renninger, Sr. Vice President, National Stone Association. February 13, 1987.

33. Brown, D. P., Kaplan, S. D., Zumwalde, R. D., Kaplowitz, M., and Archer, V. E. Retrospective Cohort Mortality Study of Underground Gold Mine Workers. In: Controversy in Occupational Medicine, Cancer Research Monograph, Vol. 2 Praeger, NY, NY pp. 335-350 (1986).

34. Virta, R. L., Shedd, K., Wylie, A. G., and Snyder, J. G. Size and Shape Characteristics of Amphibole Asbestos (amosite) and Amphibole Cleavage Fragments (actinolite, cummingtonite) Collected on Occupational Air Monitoring Filters, Chapter 47 in Aerosols in Mining and Industrial Work Environments, Vol. 2 (1983), pp. 633-643.

35. McDonald, J. C., Gibbs, G. W., Liddell, F. D. K., and McDonald, A. D. Mortality After Long Exposure to Cummingtonite-Grunerite. American Rev. Resp. Disease 1978; 118:271-277.

36. Gundersen, J. N., and Schwartz, G. M. The Geology of the Metamorphosed Biwabik Iron-Formation, Eastern Mesabi District, Minnesota. Bulletin No. 43, University of Minnesota, Minnesota Geological Survey. The University of Minnesota Press, Minneapolis, 1962 p. 123.

37. Cooper, W. C. Epidemiologic Studies of Mining Population Exposed to Nonasbestiform Amphiboles, Literature Review Prepared for The National Stone Association, January 22, 1988, p. 5.

38. Higgins, I. T. T., Glassman, J. H., Mary, S. O., and Cornell, R. G. Mortality of Reserve Mining Company Employees in Relation to Taconite Dust Exposure. American Journal of Epidemiology 1983; Vol. 5 118:710-719.

39. Cooper, W. C., Wong, O., and Graebner, R. Mortality of Workers in Two Minnesota Taconite Mining and Milling Operations. Journal of Occupational Medicine 1988; 30:507-511.

40. Kelse, J. W., and Thompson, C. S. The Regulator and Mineralogical Definitions of Asbestos and Their Impact on Amphibole Dust Analysis, American Ind. Hygiene Assoc. J. (1989) 50:11, 613-622.

41. Brown, D. P., Wagoner, J. K., Dement, J. M., Zumwalde, R. D., Gamble, J. F., Fellner, W., and DeMeo, M. J. Occupational Exposure to Talc Containing Asbestos. NIOSH Pub. No. 80-115, 1980.

42. Thompson, C. S. Consequences of Using Improper Definitions for Regulated Mineral. In Definitions for Asbestos and Other Health-Related Silicates (STP-834) Phil., PA: ASTM, 1984, P. 182.

43. Harvey, A. M. Tremolite in Talc - A Clarification in Industrial Minerals. Worchester Park Survey, England: Metal Bulletin Limited, 1979, pp. 23-59.

44. Dunn Geoscience Corporation. An Evaluation of Mineral Particles at Gouverneur Talc Company 1975 and 1982: A Comparison of Mineralogical Results Between NIOSH and DGC. Contract analysis and report to the R. T. Vanderbilt Company, Inc. January 4, 1985.

45. Langer, A. M., and Nolan, R. P. Mineralogical Characterization of Vanderbilt Talc Specimens. Contract analysis and report to the R. T. Vanderbilt Company, Inc. 1989.

46. Virta, R. L. The Phase Relationship of Talc and Amphiboles in a Fibrous Talc Sample. U.S. Department of the Interior. U.S. Bureau of Mines Report of Investigations #8923 p. 8 (1985).

47. Crane, Daniel T. Memorandum from OSHA Salt Lake City Analytical Laboratory — Microscopy Branch to Dr. Greg Piacitelli, NIOSH — Morgantown, West Virginia, November 26, 1986.

48. Wylie, A. G. Report of Investigation — The University of Maryland, Dept. of Geology. Sample analysis report to Mr. Dennis Race (sample from the House of Ceramics in Memphis — GTC talc — NYTAL 100) February 13, 1987.

49. Wylie, A. G. Analysis Report to Guy Driver regarding R. T. Vanderbilt Talcs, NYTAL 300 and NYTAL 400. March 8, 1983.

50. Wylie, A. G. Affidavit for submission to the OSHA docket. November 1, 1984.

51. Griegner, G., and Walter, C. McCrone Associates Analysis of Tremolitic Talc FD-14. April 5, 1972.

52. Evaluation of NIOSH Studies of Mortality of Workers Employed by the Gouverneur Talc Co., R. T. Vanderbilt Company, Inc. between 1948-1983. Re: Gamble, J. and Piacitelli: MHETA 86-012. 1988 Report of Ad Hoc Subcommittee, Board of Scientific Counselors, NIOSH 1989.

53. Reger, R., and Morgan, W. K. C. On Talc, Tremolite and Tergiversation. British Journal of Medicine — Editorial in press.

54. Gamble, John (NIOSH). "Critique of NIOSH position of Vanderbilt talc as an asbestiform mineral increasing the risk of lung cancer is exposed workers." Memorandum to Director, DRDS, November 22, 1985.

55. Cooper, W. C. Letter to the R. T. Vanderbilt Company, Inc. commenting on the NIOSH study of New York Tremolitic Talc. October 4, 1982.

56. Morgan, Robert W. "A Review of the Literature on the Carcinogenicity of Asbestiform and Nonasbestiform Actinolite, Tremolite and Anthophyllite," for the National Stone Association, February 4, 1988.

57. Boehlecke, Brian A. "Review and Comments on the Evidence for Human Health Effects from Exposure to Nonasbestiform Tremolite, Actinolite and Anthophyllite and the Regulation of Occupational Exposures," for the American Mining Congress, 1988.

58. Morgan, W. K. C., MD. Letter to Mr. John Martonik (OSHA Standards Group) critiquing OSHA draft of its revised asbestos standard, August 23, 1983.

59. Stille, W. T., and Tabershaw, I.R. "The Mortality Experience of Upstate New York Talc Workers," Journal of Occupational Medicine, Vol. 24 #6 (June 1982).

60. Brown, D. P., Dement, J. M., and Beaumont, J. J. (NIOSH). Letter to the Journal of Occupational Medicine forwarded to Irving R. Tabershaw, MD, August 13, 1982.

61. Lamm, S. H., Levine, M., Starr, J. A., and Tirey, S. L. "Analysis of Excess Lung Cancer Risk in Short-term Employees," American Journal of Epidemiology Vol. 127 #6 (1988). Based on an expanded manuscript entitled, "Absence of Lung Cancer Risk From Exposure to Tremolitic Talc" (February 1986).

62. Brown, D. P. (NIOSH). Review of Analysis of R. T. Vanderbilt Talc Employees. Memorandum to Director DSDTT, August 18, 1983.

63. Glenn, R. E. (NIOSH). Recommended Action on MHETA #86012 Gouverneur Talc. Memorandum to Director, NIOSH, November 18, 1987.

64. McConnell, E., Rutter, H. A., Ulland, B. M., and Moore, J. A. "Chronic Effects of Dietary Exposure to Amosite Asbestos and Tremolite in F344 Rats." Environmental Health Perspectives Vol. 53, p. 27-44 (1983).

65. Wylie, A. G. Letter to Rick Renninger — National Stone Association regarding Addison/Davis Tremolite from Dorney. July 1989.

66. Pott, F., Huth, F., and Friedrichs, K. H. Tumorigenic Effects of Fibrous Dusts in Experimental Animals. Environmental Health Perspectives 1974. 9:313-315.

67. Steenland, K., Brown, D.: Mortality Study of Gold Miners Exposed to Silica and Nonasbestiform Amphibole Minerals: An Update with 14 More Years of Follow-up. American Journal of Industrial Medicine (1995) 27:217-229

68. Cooper, W. C., Wong, O., Trent, L. S. and Harris, F.: Mortality of Workers in Two Minnesota Taconite Mining and Milling Operations - an Update. Journal of Occupational Medicine (1992) 34:1173-1180.

69. Van Orden, Drew (R. J. Lee Group, Inc.): Analytical Report to the R. T. Vanderbilt Company. Project AOH803000, July 30, 1988.

70. Brown, D. P. et al (NIOSH): Health Hazard Evaluation Report HETS 90-390-2065 MHETA 86-012-2065, 1990.

71. Gamble, J.: "A Nested Case Control Study of Lung Cancer Among New York Talc Workers", International Archives of Occupational Environmental Health 64:449-456 (1993).

72. Wylie, A. G., Mossman, B. T. et al: Mineralogical Features Associated with Cytotoxic and Proliferative Effects of Fibrous Talc and Asbestos on Rodent Tracheal Epithelial and Pleural Mesothelial Cells; Toxicology and Applied Pharmacology 147,000-000 article no. T0978276, 1997.

73. Honda, Y., Beall, C., Delzell, E., Oestenstad, K., Brill, I., Mathews, R.: "Mortality In Talc Workers" accepted for publication May 10, 2002; The Annals of Occupational Hygiene.

74. Wylie, A. G., and Verkouteren, J. R.: Amphibole asbestos from Libby, Montana: Aspects of Nomenclature. American Mineralogist (2000) 58:1540-1542.

75. Wylie, A. G., Bailey, K. F., Kelse, J. W., and Lee, R. J.: The Importance of Width in Asbestos Fiber Carcinogencity ad Its Implications for Public Policy. American Industrial Hygiene Association Journal (1993) 54:239-252.

76. Steel, E., Wylie, A. G. "Mineral Characteristics of Asbestos," article in Geology of Asbestos Deposits, P. H. Riodon, ed., Society of Mining Engineers of AIME, P. 93-100 (1981).

77. Wylie, A. G. "Factors Affecting Risk from Biologically Active Minerals," Metallurgy and Exploration Symposium: Mineral Dusts - Their Characteristics and Toxicology." Washington, D.C. September (1996).

78. Baris, Y.I., "Asbestos and Erionite Related Chest Diseases." Pub. Somih Ofset Matbaackilik Ltd. Co. Ankara-Turkey (1987).

APPENDIX I

Definition Contributors and Supporters (Partial List)

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  David Stith — Head of Geochem Sec., Ohio Dept. of Natural Resources

* Direct Contributors

APPENDIX II

INTRODUCTION:

As shown in this pictorial presentation, the properties of asbestos are unique. These properties include very long, thin, fibrillar fiber bundles that are flexible and strong. The ability of excessive exposure to asbestos to cause serious pulmonary disease has been extensively studied and documented.

Analytical procedures designed to identify and quantify asbestos must incorporate the unique characteristics of asbestos as fully as possible if the method is to be as specific to asbestos as possible. Minimizing mischaracterization (false positives and negatives) defines the value of any analytical protocol and is a key element to meaningful measurement of risk.

The most common analytical approach used for airborne asbestos fiber quantification is phase contrast microscopy (PCM). PCM methods typically measure airborne elongated particulate with a length to width ratio of at least 3 to 1 and a length 5 μm or greater (e.g. NIOSH 7400). Since there is little reason to measure airborne elongated particulates other than for asbestos, this relatively cheap, simple to apply method, is most often used to collect and count asbestos fibers. Although PCM will count all asbestos fibers observable under light microscopy (400X), it unfortunately also counts elongated nonasbestiform cleavage fragments, insect legs and any other elongated particulate collected on the air monitoring filter that meet the simple dimensional counting criteria. Consequently, the simple PCM method works well in an environment where commercial asbestos is known to be the predominate elongated particle in the air being sampled. In mixed dust environments, the PCM method must be enhanced to more selectively measure asbestos from the other particulate in the sample.

Fiber counting criteria employed in microscopy methods are often mistakenly viewed as the *definition* of an asbestos fiber. The fiber counting criteria employed in most PCM methods are, in fact, merely arbitrary parameters used to promote consistency in fiber counting. The 5 μm minimum length, and the 3:1 minimum aspect ratio criteria, originated in England's asbestos textile mills as a means to improve reproducibility of commercial asbestos fiber measurements. These counting parameters were **not** deemed to be the dimensions that corresponded to a specific health risk (Holmes, 1965).

The PCM method is unable to detect fibers below approximately 0.2 μm in width and has always been viewed as an ***index of exposure*** versus an absolute measure of all fibers present in a sample. It is also unable to characterize the mineral composition or crystal structure of the particles examined. Again, in an environment where it is known that the primary elongated particle present is commercial asbestos, these limitations become less important. In environments where there are mixed dusts and where asbestos may or may not be present, the PCM method, with its simple counting criteria, becomes wholly inadequate.

This inadequacy is clearly demonstrated in the 1986 OSHA asbestos standard preamble discussion of its quantitative risk analysis and its decision to exclude studies of Canadian asbestos miners. The asbestos miners were excluded because the fiber count dose-response relationship observed differed significantly from the fiber count dose-response observed for other asbestos exposed populations under review by OSHA.

OSHA found that the miners had been exposed to similar or higher "fiber" concentrations than textile or other commercial asbestos exposed populations but showed significantly less adverse health effects. The asbestos "fiber" exposure was based solely on 3 to 1 aspect ratio or greater, 5 μm or longer, light microscopy fiber counts.

In Canadian asbestos mines, asbestos often represents no more than 5% of the ore being mined with the remaining host rock predominantly being the nonasbestiform serpentine mineral, antigorite. The apparent "asbestos" fiber count in this mixed mineral dust environment therefore included antigorite cleavage fragments as well as chrysotile fibers. The inclusion of elongated nonasbestiform fragments, which have never been shown to produce asbestos-like disease, in the fiber count significantly inflated the asbestos dose reported without a corresponding increase in response.

Had nonasbestiform cleavage fragments been properly identified and excluded from the asbestos fiber count, the asbestos risk observed for the Canadian asbestos miners may well have been comparable to that observed among the commercial asbestos exposed groups that were used in the OSHA risk analysis (Wylie and Bailey, 1992). In this example, analytical methods that failed to address what is and is not asbestos clearly impacted risk assessment.

Sub-light microscopic methods such as transmission electron microscopy (TEM) and scanning electron microscopy (SEM) present another analytical confounder when improperly applied. In contrast to the limitations of PCM, electron microscopic analytical methods such as TEM are capable of detecting asbestos fibers well below the resolution limit of the light microscope, identifying mineral type and can address crystal growth distinctions important to proper asbestos identification.

Despite the elevated costs associated with electron microscopic analyses, the desire to identify and quantify lower and lower asbestos levels in building materials and in asbestos abatement projects has contributed significantly to the proliferation of TEM laboratories across the country. These types of samples are typically limited to chrysotile, undergo highly prescriptive analytical protocols and require little to no mineralogical expertise in the analysis. For all its sophistication and sensitivity, electron microscopy presents a different set of analytical variables that will affect risk assessments when its results are improperly interpreted or improperly compared to health exposure standards.

The health literature on asbestos exposed populations overwhelmingly involves exposure to commercial asbestos. Asbestos exposure levels reported in epidemiological studies used to establish exposure limits have been obtained through light microscopy methods. Permissible exposure standards for airborne asbestos are based upon this light microscopy ***index of exposure***. Efforts to use electron microscopic analytical data for risk assessment purposes must include a means to correlate results to what would be observable under light microscopy.

Unfortunately, the difference between asbestos fibers observed under the light microscope and asbestos fibers observed by electron microscopy is highly variable. This variability is influenced by asbestos type, how the fibers become airborne and the nature of fiber bundle separation in each exposure setting. "One size fits all" correlations are difficult (if not impossible) to reliably establish. Electron microscopy views only a very tiny fraction of the sample being studied and is therefore a poor quantification tool. Unless coupled with other investigation techniques, electron microscopy does not adequately address populations of particles in a sample. In an unknown or mixed dust environment, this is an important indicator of the asbestiform or nonasbestiform nature of a given exposure.

Electron microscopy methods are unquestionably the best analytical tool for asbestos identification, but not for quantification unless coupled with other methodologies. The health significance of asbestos fibers observed only through electron microscopy and not correlated to PCM-observable exposure levels, is unknown at this time. The authors are not aware of any studies of asbestos-related disease where the asbestos exposure was not readily observable under light microscopy.

SOLUTIONS:

While the strengths and weaknesses of every asbestos analytical approach has not been addressed, most analysts would agree that there is no perfect, single asbestos analytical methodology. Certainly each approach is made more reliable in the hands of experienced, knowledgeable analysts. Effectively combining different analytical tools in a tiered approach can overcome individual method weaknesses, control costs and yield highly reliable results.

The following analytical guides reflect asbestos analytical approaches considered most reliable for asbestos identification and quantification. In each case, the unique characteristics of asbestos fibers and asbestos fiber populations are used to the fullest extent possible.

In the case of PCM, for example, dimensional fiber counting criteria that are more specific to asbestos are recommended as a more sensitive screening technique if standard PCM counts exceed established asbestos fiber permissible exposure limits. This additional PCM step significantly improves PCM as an inexpensive, easy to apply asbestos screening tool and assists the investigator in deciding if more specific, more costly analysis is warranted.

A polarized light microscopy method for bulk analysis is also provided. This method is designed with more guidance into what is and is not asbestos and, in the hands of a skilled analyst with mineral expertise, can be more informative than electron microscopic analysis.

The effective utilization of any asbestos analytical methodology, used singularly or in combination with others, does require a clear understanding of what asbestos is and what it is not. Methodologies that do not or can not recognize these distinctions should not be used.

REFERENCES:

National Institute for Occupational Safety and Health
NIOSH Manual of Analytical Methods. 3 Ed.
(DHHS/NIOSH Pub. No. 84-100). Washington, D.C.:
Government Printing Office, 1984. Method #7400.

Holmes, S.: Developments in Dust Sampling and Counting Techniques in the Asbestos Industry. Annals New York Academy of Sciences. pp. 288-297 (1965).

Differential PCM Fiber Counting Methodology for Air Samples

BACKGROUND:

In environments where the presence of asbestos is unknown or may be present as a mixed dust, the NIOSH 7400 PCM membrane analytical method must be supplemented with differential counting criteria to assist in determining what proportion of the dust is asbestiform and what part is not. This need for differential counting was recognized by the Occupational Safety and Health Administration (OSHA) in its final asbestos standard published in 1994 (Fed Reg. Vol. 59, No. 153, pp. 41073 - 41079 - Aug. 1994).

There is also concern among some researchers that abandonment of the traditional fiber counting criteria (fibers with a minimum length of 5 µm and a length to width aspect ratio of at least three to one) would forsake the historical database that has been created over many decades. The simplistic counting criteria alone, derived from an effort to improve analytical consistency in commercial asbestos textile exposure samples in the 1960s, is totally inappropriate for noncommercial asbestos exposure environments. Recognizing the fundamental morphological differences between asbestiform and nonasbestiform particle populations, the method must address those differences.

METHOD SUMMARY:

To satisfy historical preservation of exposure trends, the NIOSH 7400 method must be performed. Where the fiber count reaches or exceeds 0.1 fiber/cc (or the current exposure limit), supplemental measurements that allow a better characterization of the asbestiform nature of the sample must be done. These measurements will necessitate the use of a modified Walton Beckett graticule that assists in the measurement of those 3:1 or greater aspect ratio and 5 µm and longer particles that are equal to and longer than 10 µm and less than or equal to 0.5 µm in width. All fiber bundles need to be counted. This modified graticule is shown in Figure 1.

If the population of fibers has 50 % equal to or longer than 10 µm or if 50% of the fibers are equal to or less than 0.5 µm in width (unless a bundle), then the exposure can be considered to be asbestiform.

Samples that reflect an asbestiform nature must have PCM observable fibers (widths between 0.15 and 0.5 µm or bundles) analyzed by electron microscopy. Analysis by electron microscopy will evaluate morphology, chemistry and SAED if using TEM. The percentage PCM fibers that are regulated asbestiform fibers is then calculated and compared to the permissible exposure limit.

Mineralogical expertise is needed for those samples requiring electron microscopy and the standards for classifying amphibole minerals must conform with the International Mineralogical Association recommendations (Leake, B.E., Nomenclature of Amphiboles. American Mineralogist. Vol. 82, 1019 - 1037, 1997).

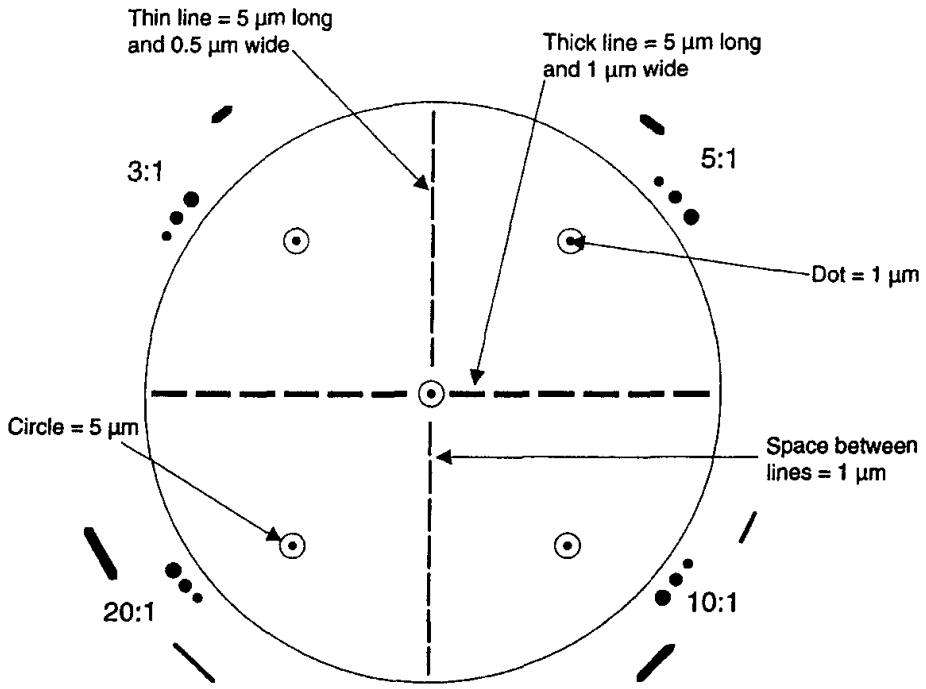

Figure 1: Modified Walton Beckett Graticule (RIB Graticule)

PCM Screen for Asbestiform Structure Determination

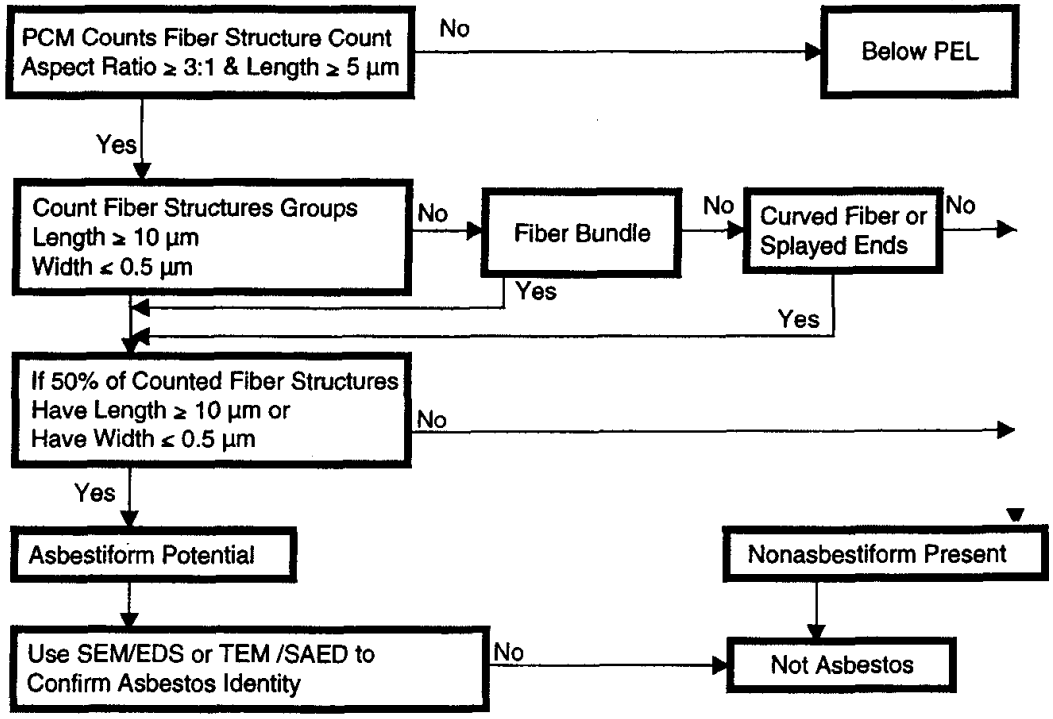

Figure 2: PCM Discriminate Counting and Analysis Procedure

Standard Method of Testing for Asbestos Containing Materials by Polarized Light Microscopy

1. SCOPE

1.1 The method describes the procedures for the determination of the presence or absence of six types of asbestos: chrysotile-asbestos, grunerite-asbestos (amosite), crocidolite (riebeckite-asbestos), anthophyllite-asbestos, tremolite-asbestos and actinolite-asbestos and for the determination of a quantitative estimate of the percent of asbestos. This method may be applied to bulk materials other than building materials but the accuracy of the method under these circumstances is not characterized. For non-building materials, there may be more interference with a greater possibility for false positives or fibers dispersed below the resolution of the light microscope yielding a higher possibility of false negatives. When the content of asbestos in a sample is close to the 1% level, other more precise methods of quantification may be necessary if it is important to determine whether or not asbestos content is more or less than 1% by weight. This distinction may be important because the EPA defines asbestos-containing materials as those materials containing greater than 1% asbestos (Ref. 2 and 3).

2. APPLICABLE DOCUMENTS

2.1 U.S. Environmental Protection Agency, "Interim Method for the Determination of Asbestos in Bulk Insulation Samples," EPA 600/M4-82-020, Dec. 1982.

2.2 U.S. Environmental Protection Agency, "Guidance for Controlling Asbestos-Containing Materials in Buildings," EPA 560/5-85-024, 1985.

2.3 U.S. Environmental Protection Agency, "Asbestos-Containing Materials in School Buildings: Guidance for Asbestos-Analytical Programs," EPA 560/13-80-017A, 1980 (under revision).

2.4 ASTM STD 834, Definitions for Asbestos and Other Health-related Silicates, B. Levadie, ed., ASTM, 1916 Race Street, Philadelphia, PA 19103, 1984.

3. TERMINOLOGY

3.1 Asbestos: A commercial term applied to a group of highly fibrous silicate minerals that readily separate into long, thin, strong fibers of sufficient flexibility to be woven, are heat resistant and chemically inert, and possess a high electric insulation, and therefore, are suitable for uses (as in yarn, cloth, paper, paint, brake linings, tiles, insulation, cement, fillers, and filters) where incombustible, nonconducting, or chemically resistant material is required. Federal regulation of asbestos is restricted to chrysotile-asbestos, grunerite-asbestos (amosite), crocidolite (riebeckite-asbestos), anthophyllite-asbestos, tremolite-asbestos and actinolite-asbestos.

3.2 Asbestiform: said of a mineral that is like asbestos, i.e., crystallizes with the habit of asbestos. Some asbestiform minerals may lack the properties, which make asbestos commercially valuable such as long fiber length and high tensile strength. All asbestos exhibits a fibrillar structure, i.e., parallel growth of fibrils in bundles. Under the light microscope, the asbestiform habit is generally recognized by the following characteristics:

3.2.1. mean aspect ratios ranging from 20:1 to 100:1 or higher for fibers longer than 5 μm.
3.2.2. very thin fibrils, usually less than 0.5 μm in width, and
3.2.3. two or more of the following:
a. parallel fibers occurring in bundles
b. fiber bundles displaying splayed ends
c. matted masses of individual fibers, and
d. fibers showing curvature

3.3 Fiber: an elongated single crystal or similarly elongated polycrystalline aggregate.

3.4 Fibril: the smallest unit fiber in a bundle of fibers characteristic of the asbestiform habit.

4. SUMMARY OF THE METHOD

4.1 Bulk samples of building materials taken for asbestos identification are first examined with a low-power binocular microscope for homogeneity, the presence or absence of fibrous constituents, preliminary fiber identification, and an estimate of fiber content. Possible identification of fibers or the confirmation of the absence of fibers is made by analysis of subsamples with the polarized light microscope.

5. SIGNIFICANCE AND USE

5.1 This method of testing is applicable to building materials including insulation, ceiling tiles, surface coatings, asbestos board, pipe coverings, etc. It is not recommended for floor tiles. However, if fibers can be liberated from a non-friable matrix, they can be identified by this method.

5.2 If the estimate of the percentage of asbestos in a sample is close to the 1% by weight level, other methods of quantification may be necessary if it is important to determine whether or not asbestos content is more or less than 1% by weight. This distinction may be important because the EPA defines asbestos-containing materials as those materials containing greater than 1% by weight asbestos (Ref. 2 and 3).

5.3 The details of the methods used to determine the optical properties of minerals are not included in this method. The method assumes that the analyst is proficient in making these measurements.

6. INTERFERENCES

6.1 Cellulose may have approximately the same index of refraction as chrysotile-asbestos. For this reason, it is frequently confused with chrysotile. However, cellulose fibers frequently pinch and swell along their length, exhibit internal cellular structure, and lack splayed ends: they are not composed of bundles of smaller fibers.

6.2 Cleavage fragments of many natural minerals including amphiboles, talc, gypsum, wollastonite and vermiculite may appear as elongated anisotropic particles. The aspect ratio of these particles may be as great as 20:1. Therefore, aspect ratio alone is not sufficient for the identification of asbestos. Other properties of the asbestiform habit, such as curved fibers, fiber bundles exhibiting splayed ends, and fibers with aspect ratios in excess of 20:1 must be observed in order to be sure asbestiform material is present in the sample. However, these properties need not be characteristic of every fiber or fiber bundle in the sample. Therefore, once asbestos is known to be present, other properties such as index of refraction and aspect ratio can be used to identify asbestos and determine which particles will be counted in making a quantitative estimate of the amount of asbestos in the sample.

6.3 Sprayed-on binder materials may coat fibers and affect color or obscure optical characteristics. Fine particles of other materials may also adhere to fibers. Occasionally, procedures other than those described in this test method may be helpful if the analyst is unable to observe fibers clearly. Some of these are described in Reference 1.

6.4 Vermiculite may be confused with chrysotile because it has a similar index of refraction and, while it is not fibrous, its extinction characteristics under crossed polars may give the impression that the particles are composed of masses of matted fibers. The problem is compounded by the fact that chrysotile and vermiculite are a common mixture in sprayed-on coatings.

6.5 Certain materials may be found in construction materials, which are fibrous or asbestiform but which are not asbestos. Those include but are not limited to fibrous talc, fibrous brucite (nemalite), zeolites and dawsonite.

6.6 Man-made fibers such as carbon, aluminum oxide, polyamides (nylon), polyester (Dacron) and polyolefins (polyethylene), and rayon are occasionally encountered in building materials.

6.7 Fibrous glass including both mineral wool and fiberglass is very common in building materials. Its isotropic character makes it readily distinguishable from asbestos.

6.8 Animal hair is occasionally encountered.

6.9 Heat and acid treatment may alter the index of refraction of asbestos and change its color. Heat can cause chrysotile and amosite to turn brown and may raise the indices of refraction significantly.

6.10 Moisture can interfere with the determination of optical properties. Wet samples should be dried at a temperature less than 150°C before examination.

7. EQUIPMENT

7.1 A magnifying glass or a low power binocular microscope, approximately 10-45x, with built-in or separate light source

7.2 Forceps, dissecting needles and probes

7.3 Glassine paper or clean glass plate

7.4 Polarized light microscope complete with a port for wave retardation plate, 360 degree graduated rotating stage, substage condenser, lamp and lamp iris

7.5 Objective lenses: low power (10x); high power (40-50x). Medium power (20-25x) and very low power (2-4x) lenses are optional.

7.6 Dispersion staining objective lens (optional)

7.7 Ocular lens: 8x minimum

7.8 Eyepiece reticle: cross hair

7.9 Compensator (wave retardation plate): 550 nanometer (first-order red or gypsum)

7.10 Microscope slides

7.11 Coverslips

7.12 Mortar and pestle: agate or porcelain

8. REAGENTS

8.1 Index of refraction liquids: N_D = 1.490-1.720 in increments of 0.002 or 0.004.

8.2 Index of refraction liquids for dispersion staining: high dispersion series, N_D = 1.550, 1.605, and 1.680. (Optional. Required only if dispersion staining will be used to measure the index of refraction.)

8.3 Reference materials:

8.3.1 Asbestos Materials

a. Commercial asbestos, including amosite, chrysotile, crocidolite, and anthophyllite asbestos. (UICC Asbestos Reference Sample Set available from UICC MRC Pneumoconiosis Unit, Llandough Hospital, Penarth, Glamorgan, CF6 1XW UX and commercial distributors.)

b. Tremolite-asbestos: available from commercial distributors, such as Ward's Natural Science Establishment, Inc., P.O. Box 92912, Rochester, New York, 14692-9012.

c. Actinolite-asbestos: source to be determined (very rare; not used commercially).

8.3.2 Suggested Matrix and Non-asbestos materials.

a. Cellulose

b. Vermiculite: source to be determined.

c. Non-asbestiform amphiboles: available from commercial distributors, such as Ward's Natural Science Establishment, Inc., P.O. Box 92912, Rochester, New York 14692-9012.

d. Other silicates, such as fibrous talc, wollastonite, gypsum, nemalite (brucite): available from commercial distributors, such as Ward's Natural Science Establishment, Inc., P.O. Box 92912, Rochester, New York 14692-9012.

e. Synthetic fibers, such as fiberglass and mineral wool.

9. PRECAUTIONS

9.1 This method involves the analysis of material (asbestos), which may be hazardous if inhaled. It does not address the safety problems associated with its use. In addition, it should be noted that some immersion oils manufactured prior to 1978 might contain Polychlorinated Biphenols (PCB). PCB's have been identified as hazardous materials. It is the responsibility of whoever uses this method to establish appropriate safety and health practices to ensure that asbestos is not inhaled and exposure to PCB does not occur.

10. SAMPLING

10.1 Samples should be taken in the manner prescribed in Reference 2. Information on design of sampling and analysis programs may be found in Reference 3. If there are any questions about the representative nature of the sample, another sample should be requested before proceeding with the analysis.

11. GENERAL METHOD DESCRIPTION

11.1 Bulk samples of building materials are first examined with a low power binocular microscope or magnifying glass for homogeneity, the presence or absence of fibrous constituents, preliminary fiber identification and an estimate of fiber content.

11.2 Positive identification of fibers or the confirmation of the absence of fibers is made by analysis of subsamples with the polarized light microscope according to the outline presented in Table I. The optical properties of six types of asbestos are given in Table II. The use of plane polarized light allows the determination of index of refraction parallel to elongation. Morphology and color are observed. Orientation of the two polarizers such that their vibration directions are perpendicular (crossed polars) allows the distinction between anisotropic and isotropic materials to be made. It also allows observation of the birefringence and extinction characteristics of anisotropic particles. When a compensator is inserted into the optical path, the sign of elongation of the particle can be determined. Also, the fibrillar structure of asbestos is most evident under crossed polars.

11.3 Identification of the fibrous constituents is facilitated by comparison of the unknowns to materials in the reference collection.

11.4 A quantitative estimate of the amount of asbestos present is derived from the combination of the estimate made from slide preparations and the estimate of total fiber made from examination of the bulk sample.

12. SAMPLE PREPARATION

12.1 For initial observation, the sample should be placed on a clean glass plate or glassine paper and placed under the binocular microscope or examined with a magnifying glass. Color, the presence or absence of fibers, and homogeneity should be observed and recorded. If only an occasional fiber is observed, one or two should be isolated with forceps and prepared for examination by polarized light microscopy. A preliminary estimate of total fiber content can be made at this time.

12.2 Subsamples for polarized light microscopy are usually best prepared by using forceps to sample at several places from the bulk material. These subsamples are immersed in a refractive index liquid on a microscope slide, teased apart and covered with a cover glass. At a minimum, two slide preparations should be made.

12.3 If the material is obviously layered or comprised of two or more materials that differ in color or texture, slide preparations of each component should be made.

12.4 If the sample is not readily friable or if the sample consists of a coarse-grained matrix, a mortar and pestle can sometimes be used to crush the sample.

12.5 Other methods of sample preparation for homogenization and to remove interferences, such as milling, acid and sodium metaphosphate treatment and ashing, are not normally necessary. They are described in Reference 1.

13. IDENTIFICATION OF ASBESTOS

13.1 Positive identification of asbestos requires the determination of the following optical properties: morphology, color and pleochroism, index of refraction parallel to elongation, birefringence, extinction characteristics and sign of elongation. Techniques

for determining these properties are described in References 4 through 8. Characteristics of the asbestiform habit (morphology) are described in References 9 and 10. The sign of elongation is determined by use of a compensator and crossed polars. Index of refraction may be determined by the Becke line method (Reference 4) or by dispersion staining (Reference 8). The optical properties are given in Table II. General optical properties of silicates other than asbestos are found in References 4-7.

14. QUANTIFICATION OF ASBESTOS CONTENT

14.1 A quantitative estimate of the amount of asbestos present is most readily obtained by visual comparison of the bulk sample and slide preparations to other slide preparations and bulk samples with known amounts of asbestos present in them. Reference samples containing known amounts of asbestos will be available in the future from the National Institute of Standards and Technology, Office of Standard Reference Materials. Until these standards are available, laboratories should make their own standards for training and intra-laboratory comparison.

14.2 Point counting of slide preparations is not generally recommended. Point counting only produces accurate quantitative data when the material has uniform thickness. In practice, the thickness of asbestos-containing materials placed on a glass slide for petrographic analysis is often highly variable, rendering quantitative volume estimates inaccurate. However, the method recommended by the EPA for determining the amount of asbestos uses point counting techniques. It is described in Reference 1.

14.3 Estimates of the quantity of asbestos obtained by the method described in 14.1 above are neither volume nor weight-percent estimates. They are based on estimating the projected area from observation of the distribution of particles over the two-dimensional surface of the glass slide and on an observation of the bulk material. A basis for correcting to a weight or volume percent basis has not been established. However, the error introduced by assuming that the estimates are equivalent to weight percent is probably within the precision of the visual estimate techniques.

15. DATA PRESENTATION

15.1 The following information should be reported for each sample: color, presence or absence of asbestos, type or types of asbestos present, estimate of the area percentage of each type of asbestos present, area percentage of other fibrous materials present, and identity of other fibrous materials if known.

15.2 If the sample submitted for analysis is inhomogeneous and subsamples of the components were analyzed separately, the data for each subsample should be recorded separately. However, the separate components should be combined in proportion to their abundances and a single analysis should be provided for the sample as a whole.

15.3 Example Sample Analysis Sheet

Analysis of Asbestos in Bulk Materials

Sample Identification

Analyst:

Date:

Macroscopic Examination:

1. Size and Condition of Sample:
2. Texture: (occurrence of fibrous and other components)
3. Color:
4. Homogeneity:
5. Comments

Microscopic Examination:

1. Number and Size of Subsamples:
2. Preparation: (incl. Grinding, ashing, acid washing, ...)
3. Method of estimation if other than visual estimation:
4. Standards used for quantitation (if any):
5. Index of refraction of the immersion medium

Sample Identification:

Analysis of fibrous component:

	Component 1	Component 2
a. Morphology		
b. Color		
c. Birefringence		
d. Extinction characteristics		
e. Indices of refraction (dispersion characteristics)		
f. Sign of elongation		
g. Estimated range (percent area) of fibrous component		

Comments: (Describe any unusual characteristics or problems with analysis and if possible, briefly describe non-fibrous matrix components.)

Sample Summary

Sample Identification:

Conclusions

1. Asbestos present: yes no
2. Fibrous-nonasbestos component present: yes no
3. Number of distinct fibrous components:
4. Types of fibers:
5. Estimated range (percent area) of each fiber type:
6. (Optional information on nonfibrous components).

16. QUALITY ASSURANCE

16.1 Laboratories performing this test method should have demonstrated proficiency in the method. This would include adequate training of the analyst, an internal quality assurance program and participation in the EPA's Bulk Sample Analysis Quality Assurance Program or the National Institute of Standards and Technology Laboratory Accreditation Program for the Analysis of Asbestos. The laboratory should have a complete set of reference materials.

16.2 In order to obtain the accuracy indicated in 17.3, it is suggested that the analyst have completed a college-level course in mineralogy, had formal training in polarized light microscopy and its application to crystalline materials including instruction in the measurement of the index of refraction by the immersion method through Becke line technique and/or dispersion staining, and have experience analyzing asbestos samples. If this training is lacking, two years of participation in the EPA's Bulk Sample Analysis Quality Assurance Program with a 100% success rate is a good indication of proficiency in the application of this method.

16.3 An internal quality assurance program should involve blind samples and replicate analyses. It is also necessary to analyze blank samples to check for contamination of immersion oils, probes, slides and general sample preparation.

16.4 A record of the sample analyses should be kept that includes all the sample and analysis data. An example analysis recording form can be found in section 15.3 while the format of the record is not required, all the information detailed in the sample should be recorded for each sample.

17. PRECISION AND BIAS

17.1 The upper detection limit is 100%. The lower detection limit is less than 1%.

17.2 A preliminary evaluation of a method similar to that outlined in this document is found in Reference 11.

17.3 If used by a properly trained and experienced analyst, the accuracy in the determination of the presence or absence of greater than 1 area % asbestos is greater than 99%. If the analyst does not have the training specified in 16.2, the accuracy may be considerably reduced.

17.4 The error associated with the quantitative estimate of weight or area percent asbestos may be quite large. When the percentage of asbestos in the bulk sample is small, the error in the estimate may exceed 100% relative. Relative errors are particularly large in estimates near 1%. When the percentage of asbestos is large, however, the error is significantly reduced and may be as low as 10% relative or less. The precision and accuracy of the quantitative estimate are highly dependent on the training and experience of the analyst.

REFERENCES

1. U.S. Environmental Protection Agency, "Interim Method for the Determination of Asbestos in Bulk Insulation Samples," EPA 600/M4-82-020, December 1982.

2. U.S. Environmental Protection Agency, "Guidance for Controlling Asbestos-Containing Materials in Buildings," EPA 560/5-85-024,1985.

3. U.S. Environmental Protection Agency, "Asbestos-Containing Materials in School Buildings: Guidance for Asbestos Analytical Programs," EPA 560/13-80-017A, 1980 (or revisions).

4. Bloss, F. Donald, Introduction to the Methods of Optical Crystallography, Holt, Rinehart & Winston, 1961.

5. Kerr, Paul F., Optical Mineralogy, 4th edition, New York, McGraw-Hill, 1977.

6. Shelly, David, Optical Mineralogy, 2nd edition, Elsevier, New York, 1985.

7. Philips, W. R., and D. T. Griffen, Optical Mineralogy, W. H. Freeman & Co., 1981.

8. McCrone, Walter, The Asbestos Particle Atlas, Ann Arbor Science, Michigan, 1980.

9. Steel, E. and A. Wylie, "Mineralogical Characteristics of Asbestos," in Geology of Asbestos Deposits, P. H. Riordon, ed., SME-AIME, 1981, pp. 93-103.

10. Zussman, Jack, "The Mineralogy of Asbestos," in Asbestos: Properties, Applications, and Hazards, John Wiley and Sons, 1979, pp. 45-67.

11. U.S. Environmental Protection Agency, "Bulk Sample Analysis for Asbestos Content: Evaluation of the Tentative Method," EPA 600/4-82-021, May 1982.

TABLE I: Flow Chart for Qualitative Analysis of Bulk Samples by Polarized Light Microscopy

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

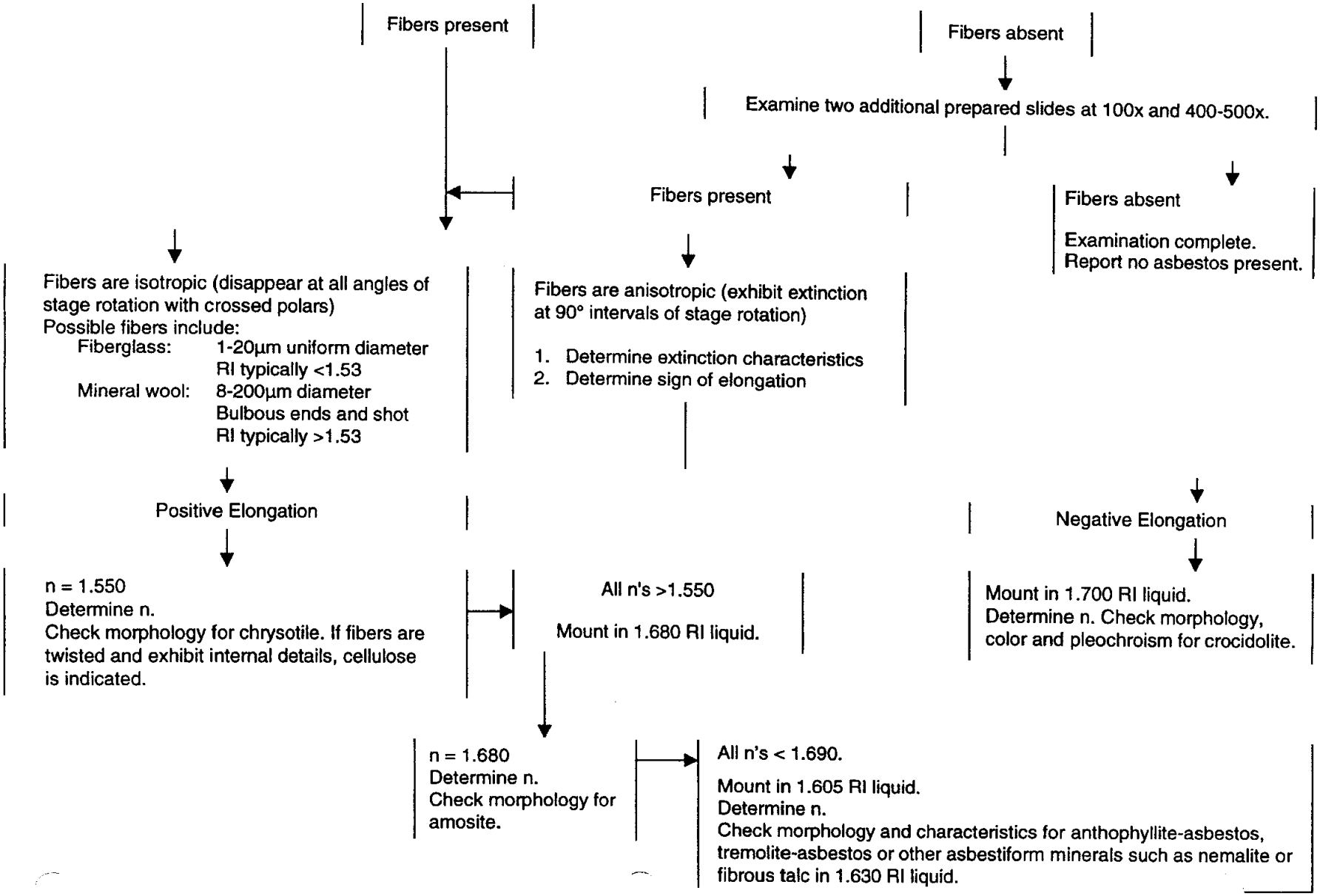

TABLE II

Mineral	Morphology and Color	Refractive Indices (Approximate Values)		Birefringence	Extinction	Sign of Elongation
		Parallel to Elongation	Perpendicular to Elongation			
Chrysotile-asbestos	Wavy fibers with "kinks" common. Large fiber bundles may show splayed ends. Colorless and nonpleochroic. Very common in building materials.	1.55	1.54	0.002-0.014	Parallel	Positive (length slow)
Cummingtonite-grunerite-asbestos (Amosite)	Straight fibers and fiber bundles. Only long fibers show curvature. Fiber bundles usually show splayed ends. Colorless to brown; may be weakly pleochroic. Common in building materials.	1.70	1.67	0.02-0.03	Parallel	Positive (length slow)
Crocidolite	Straight and curved fibers showing splayed ends are common. Blue color characteristic. Pleochroism marked. Uncommon in building materials.	1.70	1.71	0.014-0.016 Interference colors may be masked by blue color	Parallel	Negative (length fast)
Anthophyllite-Asbestos	Straight fibers and fiber bundles showing splayed ends. Colorless to light brown. Pleochroism absent. Rare in building materials.	1.63	1.61	0.013-0.028	Parallel	Positive (length slow)
Tremolite-asbestos and actinolite asbestos	Straight and curved fibers and fiber bundles. Large bundles show splayed ends. Tremolite is colorless. Actinolite is green and weakly to moderately pleochroic. Both actinolite and tremolite are extremely rare in building materials.	1.62-1.64 (tremolite) 1.64-1.68 (actinolite)	1.60-1.62 (tremolite) 1.62-1.67 (actinolite)	0.02-0.03	Parallel in most fibers. Narrow fibers may show oblique extinction ($c\Lambda Z$ up to 20°) in some samples	Positive (length slow)

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Morphological and Optical Characterization of Amphiboles from Libby, Montana U.S.A. by Spindle Stage Assisted - Polarized Light Microscopy

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KEYWORDS

Asbestos, polarized light microscopy, PLM, spindle stage, Libby, Montana, tremolite, amphibole, extinction angle, aspect ratio

INTRODUCTION

Asbestos has been a major health concern in the United States since the 1960s (1). Since then, much has been learned about common asbestos minerals and presented in several works (2-4). For instance, we know that the most commonly used asbestos variety, chrysotile - a serpentine mineral, appears to be less harmful than the more rarely used amphibole asbestos varieties (5-7). Also, several studies have shown that the fibrous variety of tremolite, i.e., tremolite-asbestos may be the most harmful of the amphibole minerals (8-12). The creation of regulatory agencies, like the Occupational Safety and Health Administration (OSHA) in 1970, and the regulations they have developed since 1972, have greatly reduced the risk of asbestos-related diseases to the point where, over the past decade, asbestos has fallen off the front page of the newspapers and out of the minds of the general public. This changed on November 18, 1999, when the Seattle Post-Intelligencer published an article about asbestos-related diseases of former miners in Libby, Montana (13). The miners worked in the world's largest vermiculite mine owned by W.R. Grace from 1963 to its closure in 1990. It had previously been owned by Zonolite Corporation with operations since 1923. The vermiculite ore was reported to contain approximately 5% tremolite-asbestos and exposure to this impurity in the ore caused an increase of asbestos-related disease in the miners. This article caught the attention of the United States Environmental Protection Agency (EPA), which arrived on the scene in a few days. Since then, millions of dollars have been spent on remediation in the area and health studies have begun.

Originally, the only amphibole believed to be in the mine in Libby was tremolite, however recent work (14) showed that two samples from the mine are winchite, which is not one of the six regulated asbestos minerals. Gunter et al. (15) confirmed these results using the same set of Libby amphibole samples in this morphological study.

ASBESTOS NOMENCLATURE – DISTINGUISHING AMPHIBOLE FRAGMENTS FROM FIBERS

Although not commonly viewed this way, there are two basic definitions of asbestos; one is physical and the other chemical. As with any definition, problems arise with natural samples based on our limitation to formally describe nature.

The physical definition of asbestos deals with its morphology or shape. Regulatory agencies consider a particle to be asbestos, for counting purposes, if its aspect ratio is 3:1 or greater and the particle is over 5 μm in length (5, 7, 16). This is, of course, very different from the physical characteristics a mineralogist would use – that the particle must have a fibrous form (see reference 19 for an overview of asbestos terms).

The chemical definition of asbestos used by regulatory agencies for identification includes six mineral species. These minerals are chrysotile, crocidolite, amosite, tremolite, actinolite, and anthophyllite (5, 7, 16). Chrysotile is the asbestos form of serpentine, a sheet silicate. The others in this group are all amphiboles. Crocidolite and amosite are asbestiform varieties of the amphibole minerals riebeckite and grunerite, respectively. Thus the names chrysotile, crocidolite, and amosite always denote asbestos minerals, while tremolite, actinolite, and anthophyllite can occur in

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either a non-asbestos (non-fibrous) or asbestos (fibrous) form, with the non-asbestos form being much more common in the geological environment.

There has been considerable controversy, for over 20 years, on distinguishing cleavage fragments, or single crystals of amphiboles, from fibers of amphiboles (10, 20-22). The underlying reason is that cleavage fragments, when inhaled, appear to be less harmful than fibers (12, 19, 23). Based on a review of all the existing literature, cleavage fragments of the amphibole minerals were deregulated in 1992 (23). Regulatory agencies simply use the aspect ratio to make the distinction between fragments and fibers, however, as we show in this paper (and has been shown by other researchers: 5, 16, 19, 21), this definition simply does not work. Fibers and fragments possess different physical properties and, as always, the physical properties of a mineral are directly related to its structure.

The structural difference between a fragment and a fiber is that fibers of asbestos are made up of many crystals, i.e. they are polycrystalline. They occur as fiber bundles comprised of individual fibrils, much like a rope is made of many small strands; giving asbestos its incredibly high tensile strength and flexibility (24). And, as Wylie (16) points out, common asbestos fibril sizes range from 500 Å in chrysotile to 6,000 Å in some amphibole-asbestos samples. Fragments, in turn, are single crystals. Thus, any analytical method that could distinguish polycrystalline materials (e.g., intergrown fibers) from a single crystal (e.g., growth or cleavage fragments) would work to distinguish fibers from fragments. This can be determined with polarized light microscopy on particles as small as 1 μm; however, when the particles reach a width and thickness of a few microns certain useful optical properties (i.e., extinction characteristics) become difficult to observe and measure due to lower retardation. In addition, Wylie (21) noted that monoclinic amphiboles (e.g., tremolite and actinolite) yield parallel extinction when they occur as fibers, instead of the expected inclined extinction. While this method works most of the time, it has limitations as discussed herein.

Diffraction methods (X-rays or electrons) can also be used to determine crystallinity i.e., single versus polycrystallinity. Wylie (21) showed that amphibole fibers display a polycrystalline diffraction pattern in the ab-plane. TEM methods have also been used on very small samples. When an amphibole particle is rotated about its c-axis, the electron diffraction patterns remain the same if it is a fiber, but changes if it is a single crystal (19).

Typically, cleavage fragments of amphiboles expose the (110) plane. However, it has been shown by past researchers (25) that single small crystals of amphiboles are flattened on (100); our study confirms this observation. In fact, this study shows that there is a possible relationship between crystal size and (110) or (100) surface development. It has also been shown that amphibole fibers are flattened on (100) (24, 26). Thus, we speculate that it might not be the fibrous form of the amphibole alone that poses the health risk, but the exposed surface, i.e., (110) surfaces may be less harmful than (100) surfaces and perhaps these surfaces, by exposing different planes of atoms in the mineral, may react differently in the human lung. Also, the surface area would be greater for a given volume of material as particle size decreases.

With the recent concerns at Libby, the definition of asbestos by the regulatory agencies comes into question; this should result in changes in regulations. For instance, as outlined in (15), the health risks associated with whatever amphiboles occur at Libby are significant. It appears that, regardless of species type, all amphibole-asbestos should be regulated. This might also extend to all fibrous silicates in general. For instance, erionite, a fibrous zeolite, has been shown to induce mesothelioma in very high amounts in lab animals and been linked to outbreaks of mesothelioma in Turkey (27). The common denominator in most of these health-related mineral problems is fibrous silicates, and perhaps they should all be regulated. However, quartz, which was recently upgraded to a Group 1 human carcinogen, is not fibrous (29). Again, silicates seem to be the common thread (27-32). Clearly this needs to be revised in light of Libby to include, at the least, all amphibole-asbestos. At present, we are left with only the six "asbestos minerals" being regulated.

GOALS OF THE STUDY

In this study we attempted to characterize the shape of particles and classify them as either single crystals, which we termed as fragments, or multiple crystals, which we termed as fibers. As such, photomicrographs of the samples provide a qualitative description. We made thousands of optical measurements on the samples in this study, and quantified these data in a series of descriptive tables. The "Results" and "Discussion" are divided into two distinct but complementary sections: analyses done on grain mounts, which is the common method of characteriz-

ing asbestos particles, and analyses of single particles with the aid of the spindle stage.

One of our goals for examining single particles was to aid in understanding our observations on grain mounts i.e., we could determine the precise extinction angles when the particles were mounted on the spindle stage, and to observe the morphological characteristics of the particles in 3D as compared to 2D in the grain mounts. Other researchers have measured aspect ratios for amphibole particles in grain mounts (e.g., 16-17), but none have done this with the spindle stage. With the spindle stage, the thickness, length and width can be measured so that the volume of a particle can be calculated. Wylie et al. (18) made a similar set of measurements on the thickness of smaller amphibole particles using both an SEM and TEM.

MATERIALS

Three separate samples were chosen for this study: a non-asbestos tremolite from our teaching collection (called UI tremolite herein), a NIST tremolite asbestos standard (NIST asbestos standard #1867), and amphiboles collected from the former vermiculite mine near Libby, Montana by the author (MEG) in October 1999. The UI tremolite sample was selected to represent a non-fibrous amphibole and to obtain data on cleavage fragments. The NIST tremolite was selected for a comparison to the Libby amphiboles. In general, tremolite samples were selected because the amphiboles from Libby had been reported to be tremolite. Since this project started, Wylie and Verkouteren (14) showed this not to be the case; they determined that two samples of Libby amphibole were winchite. Our ongoing research (15) also found the samples to be winchite and richterite. Nevertheless, the tremolite samples chosen for this study were used to compare differences in morphology and optical characteristics to the Libby amphiboles, because no winchite and/or richterite standards exist at this time. However, winchite-asbestos has been shown to occur in nature (33).

The Libby samples were further divided based on occurrence at the mine. Three samples were chosen. One was collected, in place, from one of the mined-out benches (15), called "outcrop" in this work. A second sample was taken from a 2 cm vein of amphibole in the biotite pyroxenite, the rock mined for vermiculite, called "vein" herein. The third was taken from an approximately 20 cm boulder consisting entirely of amphibole, which was resting on the ground in the middle of the abandoned mine, labeled "float."

EXPERIMENTAL METHODS

Two separate optical procedures were used to characterize the three different amphibole samples. One procedure employed a PLM to measure particle dimensions (i.e., length and width by use of a calibrated eyepiece), morphology, and extinction angles to determine if a particle was either a fiber or fragment in grain mounts. The second procedure used the PLM equipped with a spindle stage to measure particle dimensions (i.e., length, width, and thickness with the aid of a Vicker's image splitting eyepiece), morphology, and extinction angles as a function of orientation to determine if a particle was either a fiber or fragment.

Grain mounts were made for each of the samples by placing a small of amount of each on a standard petrographic slide with 1.55 refractive index liquid. This refractive index value was chosen so the particles could be easily seen in plane polarized light. Each sample was prepared as follows. The UI tremolite was crushed and sieved to –60 mesh (250 μm). The NIST tremolite, which was provided from NIST already comminuted, was sieved to –60 mesh (250 μm). The Libby samples were crushed, pulled apart, and sieved to –60 mesh (250 μm). An extra step was added for both the NIST and Libby samples; they were placed in acetone and ultrasonicated to further break the particles apart.

For the spindle stage study, single particles were selected from the same samples as prepared for the grain mounts. These single crystals were attached to a glass fiber with fingernail polish with their long dimension approximately parallel to the fiber and placed on the spindle stage with the aid of a goniometer head (34). By angular adjustments on the goniometer head, each particle was made parallel with the rotation axis of the spindle stage. In this manner, the width and thickness were observed and measured. Additionally, extinction angles were measured on the (hk0) planes, i.e., (100), (010), and (110) or on the planes corresponding to the widest and thinnest portions of the crystals.

RESULTS - GRAIN MOUNTS

Eleven (11) total grain mounts were prepared. One slide for each of the UI tremolite and NIST tremolite was prepared and three slides were prepared for each of the three Libby samples (outcrop, vein, float). On each slide, 100 particles were chosen at random and their width and length were measured. They were classified as either fragment or fiber based on mor-

phological and optical properties (i.e., extinction characteristics) and their extinction angles were measured. Also, each particle was briefly described. It would be impractical to list all of the data, so select photomicrographs (Figures 1-3) and a series of tables (all tables are located in the Appendix, pp. 132-138) are used to summarize it.

Figure 1 shows grain mount photomicrographs of the UI tremolite (Figs. 1A and 1B), the NIST tremolite (Figs. 1C and D), and the Libby amphibole (Figs. 1E and 1F). The photomicrographs in the left column were taken in plane-polarized light, and in the right column the same sample is photographed again but this time in crossed polars. There is a distinct increase in the aspect ratio when comparing the UI tremolite, to the NIST tremolite asbestos, to the Libby amphibole. The circled particles in Figures 1A, 1C, and 1E would be classified as asbestos if based on aspect ratio alone (12:1, 16:1, 30:1, respectively), however, the circled particle in Figure 1A is a cleavage fragment and not asbestos, as is the circled particle in Figure 1C. This distinction is made based on morphology and extinction conditions as shown in the corresponding Figures 1B and 1D.

All of the important characteristics of the particle circled in Figure 1E are difficult to show in two photomicrographs. However, morphologically, the blunt ends would indicate it is a fragment but its curvature would indicate it is a fiber. The particle shows inclined extinction in Figure 1F and it shows complete, sharp extinction as the stage is rotated. For these reasons, this particle is classified as a fragment. If the extinction had not been complete, we would not have classified it as either a fragment or a fiber because it would have showed characteristics of both fibers and fragments.

It is also noteworthy to point out that, for the UI tremolite, most of the particles are visible in both plane polarized and crossed polarized light, while this is not the case for the other two samples. The particles in the UI tremolite sample have a higher retardation because they are lying on (110) while particles in the other two samples more commonly are resting on (100). This phenomenon will be elaborated on in the "Discussion" section.

Table 1 gives the particle count based on width and length. Notice there are 100 particles for the UI tremolite and only 99 particles for the NIST tremolite asbestos; one of the particles in the NIST sample was calcite. For the Libby samples, data from the three slides were combined, yielding a total of 300 particles for each. The Libby outcrop sample had two calcite particles and the Libby vein had one.

Given the length and width data, aspect ratios were calculated for all of the samples. Table 2 lists the percentage of particles with different aspect ratio ranges for the five samples. Also given in Table 2 are the divisions of the particles into three groups: fibers, fragments, and not classified based on morphology. Table 3 merely combines the three Libby samples into one and is similar to Table 2. Table 4 is a summary of the five samples classified based on aspect ratio (Table 4A) and by morphology (Table 4B). Table 5 again lists the five samples, but this time they are broken down on a particle count based on four extinction conditions: 1) "parallel," when the particle exhibited parallel extinction, 2) "inclined," when the particle exhibited inclined extinction, (also included in this column is the average extinction angle and its standard deviation), 3) "isotropic," when the particle exhibited near-zero retardation, and 4) "cannot measure," for particles that never went extinct or had wavy extinction.

RESULTS - SINGLE PARTICLES

In order to characterize the size (i.e., length, width, and thickness), extinction characteristics, and morphology of the three samples in this study; ten (10) particles of the UI non-asbestos tremolite, twenty-five (25) particles of the NIST tremolite, and fifty (50) particles of the Libby vein samples were mounted on glass fibers and observations and measurements were made with the aid of a spindle stage equipped PLM. Tables 6, 7, and 8 list the results for length, width, thickness, aspect ratio (l/w), aspect ratio (l/t), aspect ratio (w/t), the extinction angles (measured on two different planes), and the morphological characterization of these 85 particles. Table 6 lists these results for the UI tremolite sample in two different manners. Table 6A lists measurements for the widest and thinnest directions of the particle. These were obtained by rotating the sample about the spindle axis to find the largest and smallest dimensions. For all of the particles except #4 and #10, these directions do not correspond to the (100) or (010) directions, which is to be expected for an amphibole exhibiting (110) cleavage. Particles #4 and #10 are flattened on (100), which is obvious by the fact that they exhibit parallel extinction. In Table 6B, each particle was rotated so the (100) direction was brought parallel to the stage of the microscope; this is determined by the condition of parallel extinction. Its width and extinction condition were measured on

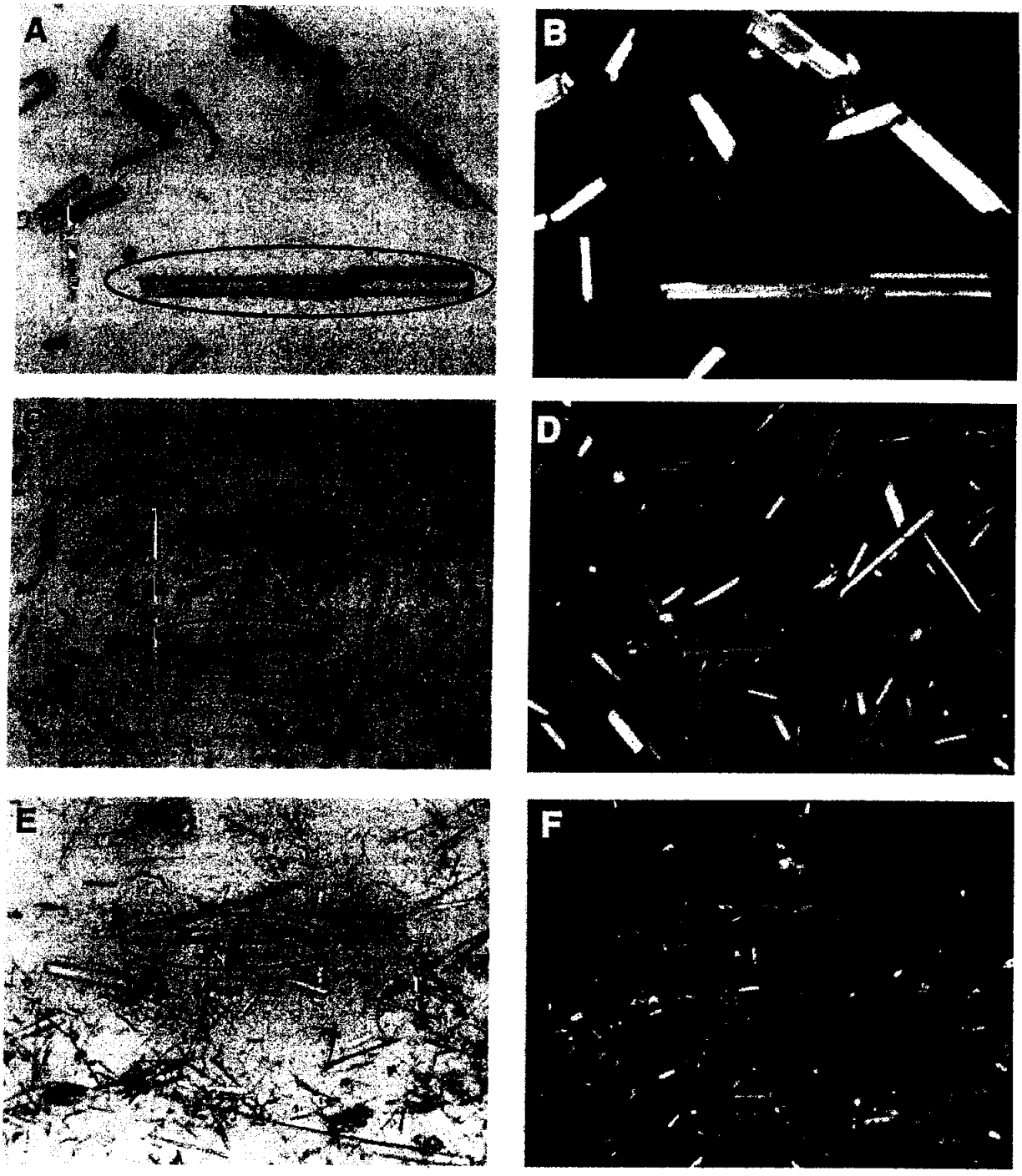

Figure 1: Photomicrographs of UI non-asbestos tremolite (A and B), NIST tremolite asbestos (C and D), and Libby amphibole (E and F). Photographs in left column correspond to those in the right column, with those in the left column taken in plane-polarized light and those in the right column taken in cross-polarized light. Circled minerals are discussed in the text. (Field of view is approximately 500 μm wide; samples are immersed in a 1.55 refractive index liquid.)

(100). The particle was then rotated and its thickness and extinction condition were measured on (010).

Figures 2 and 3 show photomicrographs of differing morphologies of the three samples immersed in a 1.55 refractive index liquid using the spindle stage. The images are of the same particles in the left and right columns, except the crystals have been rotated 90° about the spindle axis. Each particle was attached with fingernail polish (fluid-looking material) onto a glass fiber (the fibers are approximately 100 to 200 μm in diameter). Figure 2A is a photomicrograph of a single UI tremolite particle (particle #9, Table 6) viewed perpendicular to its widest direction; Figure 2B is the same particle as in Figure 2A, except the crystal has been rotated 90° to view it normal to its thinnest direction. Figures 2C to 2H are photomicrographs of the NIST tremolite sample. Figures 2C and 2D are of particle #5, Table 7 and Figures 2E and 2F are of particle #7, Table 7; both of these particles are considered fiber bundles based on their morphology. Figures 2G and 2H are NIST tremolite #21, Table 7 which is considered a fragment based on its morphology.

In Figure 3 are four samples depicting the three differing morphologies encountered in the samples from Libby. Figures 3A and 3B are of particle #7, Table 8, considered a fiber bundle, as is particle #22, Table 8 (Figures 3C and 3D). Figures 3E and 3F are of a particle considered to be a fiber mass (particle #18, Table 8). Lastly, Figures 3G and 3H show a fragment of the Libby amphibole (particle #21, Table 8). It is worth noting the orientations of the three fragments shown in this series of photomicrographs. In Figure 2A, we are looking down on the (110) surface; this is typical of cleavage fragments. In Figures 2G and 3G, we are looking at the (100) surface; this is typical of smaller amphibole crystals, i.e., they are flattened on (100).

DISCUSSION - GRAIN MOUNTS

Based solely on observation of Figure 1, there is an increase in the aspect ratio going from the UI tremolite (Figure 1A) to the NIST tremolite (Figure 1C) to the Libby amphibole (Figure 1E). The data in Tables 1 and 2 quantify this increase in aspect ratios observed in the Figures. Table 2 shows the percent non-asbestos, based on aspect ratio, to be 52% for the UI non-asbestos tremolite and 8% for the NIST tremolite asbestos. For the three Libby samples, these values are 0%, 5.4%, and 8.7% for the outcrop, vein, and float, respectively. Combining the three Libby samples, they would have 5% non-asbestos particles based on aspect ratio. Very different results are obtained basing the asbestos and non-asbestos proportions on morphology. Table 4 summarizes the data for all five samples and classifies each based on both aspect ratio (Table 4A) and morphology (Table 4B). Based on morphology, and mineralogical considerations, the entire UI tremolite sample is non-asbestos, as compared to 52% non-asbestos based on aspect ratios. For the NIST tremolite sample, 52% is non-asbestos based on morphology, while only 8% was non-asbestos based on aspect ratio. Lastly, the combined Libby sample shows the smallest amount of non-asbestos particles based on morphology, 33%, and aspect ratio, 5%. Also, note in Table 4 that we were unable to classify, as either fiber or fragment, approximately 30% of the NIST and Libby samples. Thus, the results based on aspect ratio differ significantly from those based on morphology, especially for the non-asbestos UI tremolite sample.

Our aspect ratio data yield similar results to two other studies. Wylie (35) found that a non-asbestos tremolite had 47% of the particles with an aspect ratio greater than 3 and 3% with an aspect ratio greater than 10, as compared to 48% and 4%, respectively, for the UI tremolite sample.

Basically, there are three types of particles in this study: fibers, cleavage fragments (which exhibit (110) cleavage), and single crystals, which are usually flattened on (100). Observation of extinction conditions has helped past researchers distinguish monoclinic amphibole fibers from cleavage fragments (21); in fact, OSHA mentions this method. The premise for this is that a fiber will show parallel extinction whereas a fragment will show inclined extinction.

Figure 4 shows sketches of monoclinic amphiboles with optical orientations similar to tremolite, winchite, and richterite. The lower illustration in Figure 4A represents an amphibole resting on its (110) cleavage surface. In this orientation, the sample would show inclined extinction; however, this orientation does not represent the true extinction angle (the angle between c and Z) which would be observed when a sample rested, or was viewed, on its (010) surface (lower illustration, Fig. 4B). Parallel extinction can occur because fiber bundles are elongated parallel to the c axis and the individual fiber's a- and b-axes are at random directions to this elongation; thus, the Z direction would average out over many particles to be parallel to the long direction of the fiber. This again means that an asbestos particle is really a polycrystalline material, while a fragment is a single crystal. This difference in crystallinity can be observed optically. However, if a single crystal of a monoclinic amphib-

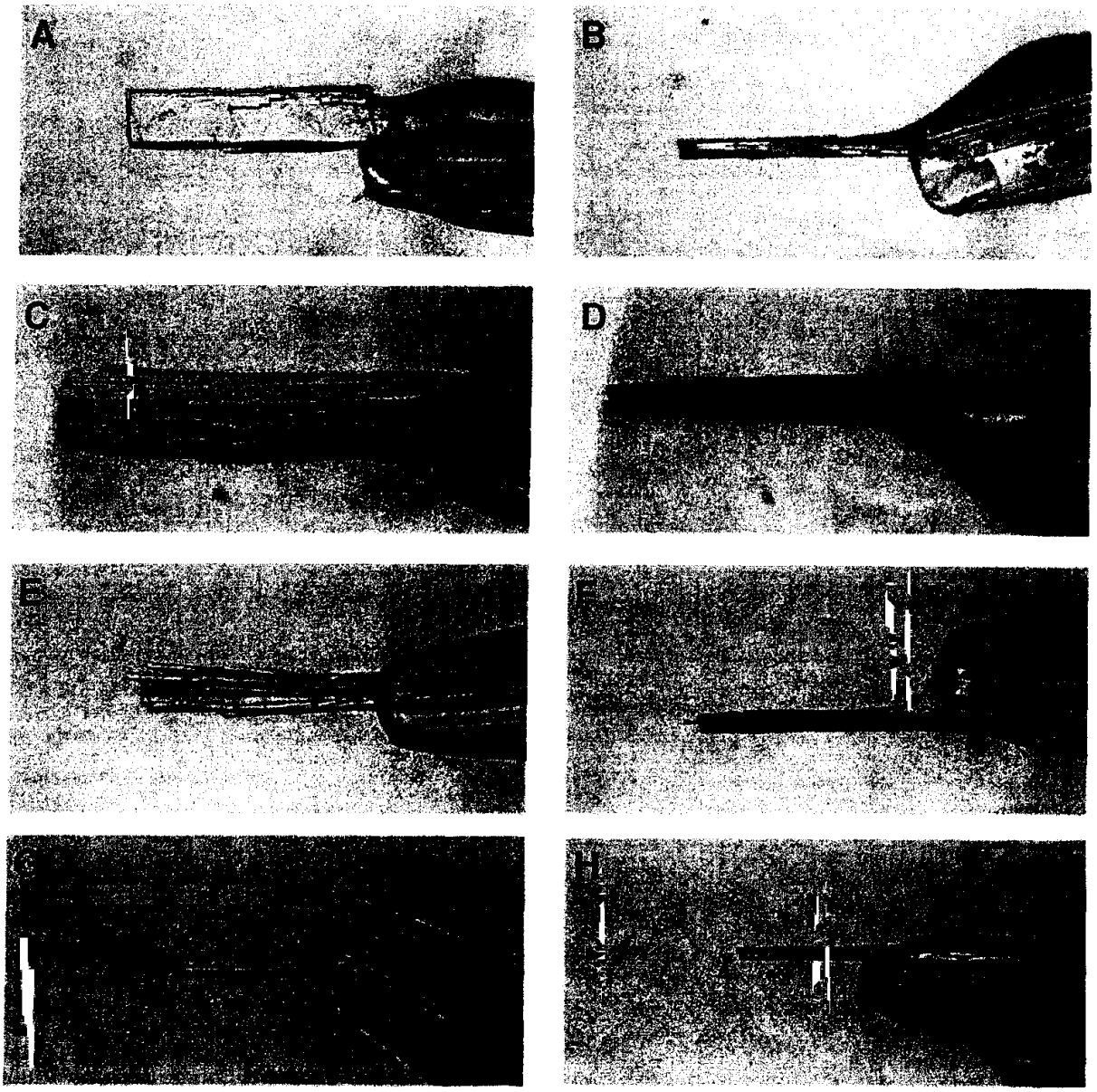

Figure 2. A) Image of UI tremolite #9 fragment (Table 6) viewed perpendicular to its thinnest direction; length is 562 μm; B) Sample in A rotated 90°; C) Image of NIST tremolite #5 fiber bundle (Table 7) viewed perpendicular to its thinnest direction; length is 728 μm; D) Sample in C rotated 90°; E) Image of NIST tremolite #7 fiber bundle (Table 7) viewed perpendicular to its thinnest direction; length is 594 μm; F) Sample in E rotated 90°; G) Image of NIST tremolite #21 fragment (Table 7) viewed perpendicular to its thinnest direction; length is 302 μm; H) Sample in G rotated 90°.

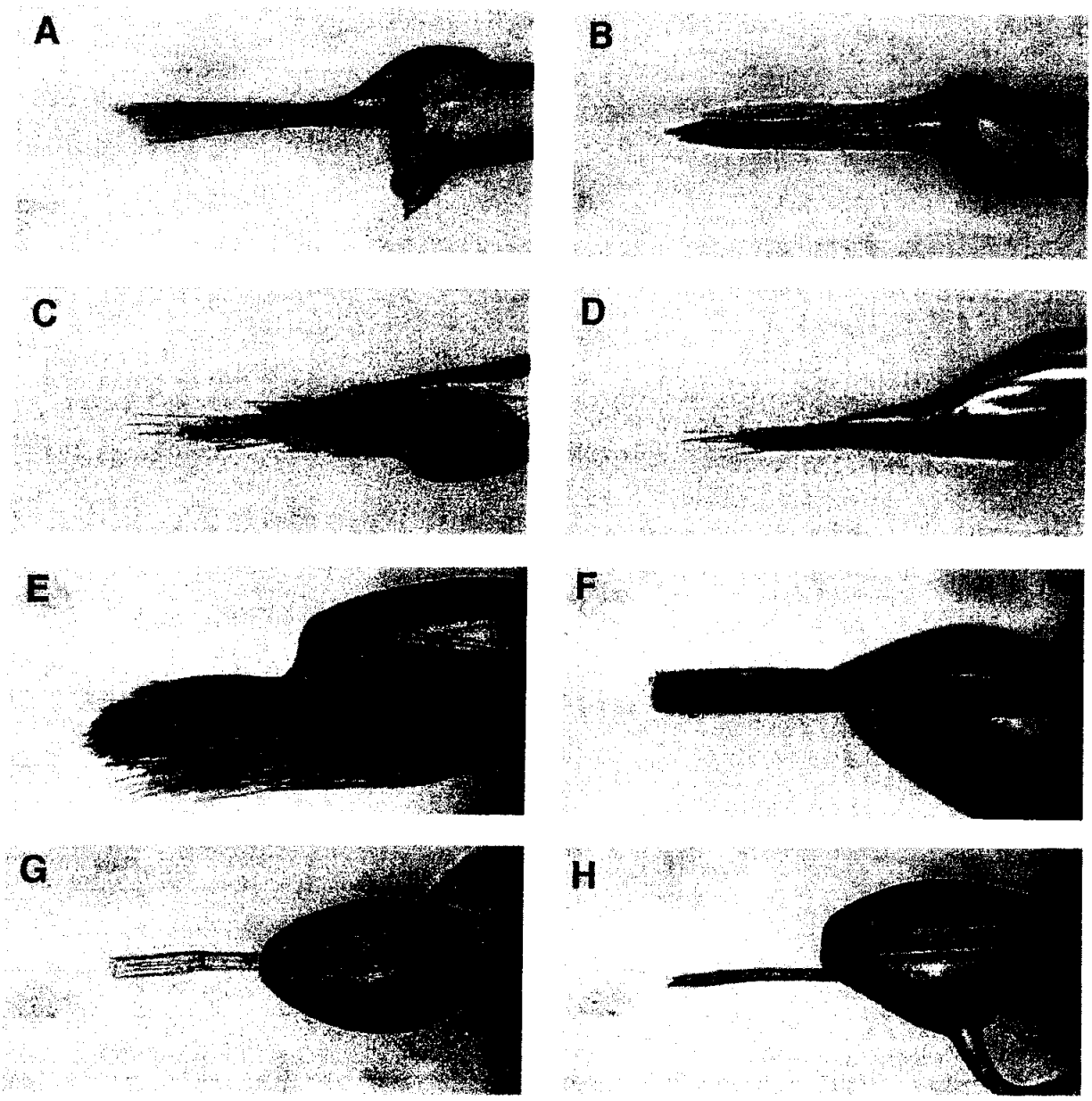

Figure 3. A) Image of Libby #7 fiber bundle (Table 8) viewed perpendicular to its thinnest direction; length is 537 μm; B) Sample in A rotated 90°; C) Image of Libby #22 fiber bundle (Table 8) viewed perpendicular to its thinnest direction; length is 512 μm; D) Sample in C rotated 90°; E) Image of Libby #18 fiber mass (Table 8) viewed perpendicular to its thinnest direction; length is 438μm; F) Sample in E rotated 90°; G) Image of Libby #47 fragment (Table 8) viewed perpendicular to its thinnest direction; length is 375 μm; H) Sample in G rotated 90°.

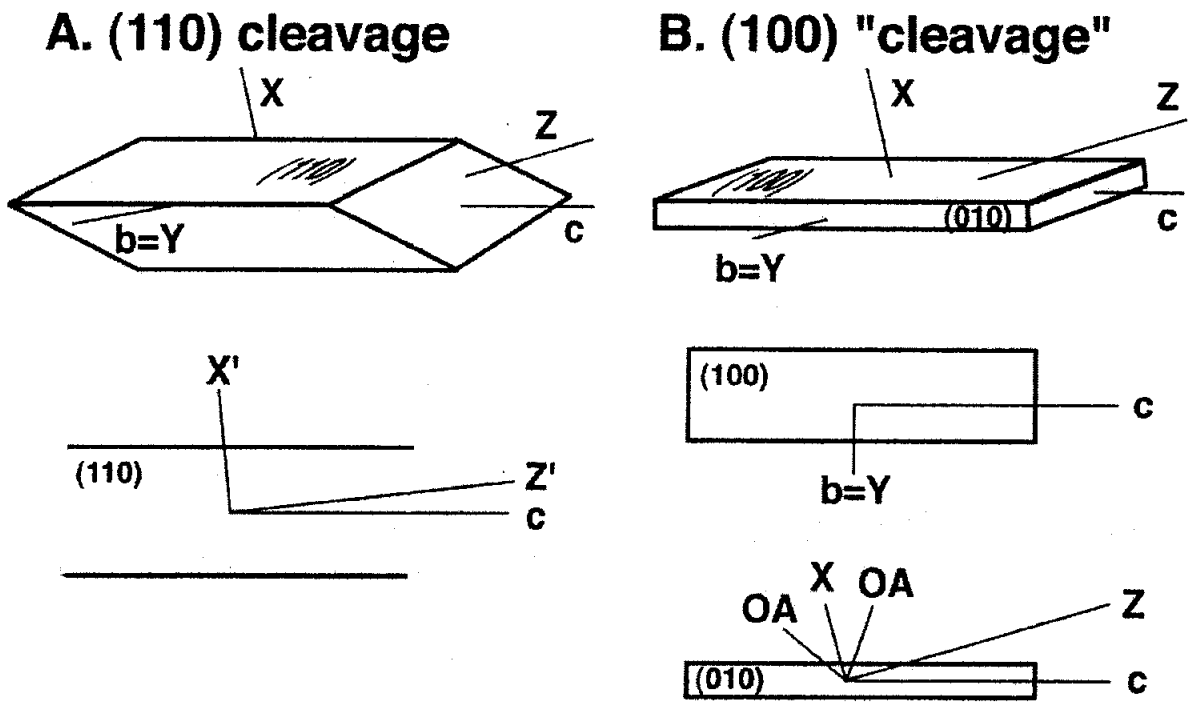

Figure 4. A) Typical cleavage fragment of a monoclinic amphibole (top) showing the (110) cleavage faces, crystallographic axes, and optical vibration directions (indicated by X' and Z'), and a similar crystal (bottom) resting on a (110) cleavage surface. B) A monoclinic amphibole (top) flattened on (100) and elongated along c, a crystal (middle) resting on (100) that would show parallel extinction (middle), and the view (bottom) looking down b on the (010) plane. The optic axes are indicated by OAs.

ole is flattened on (100), it will also show parallel extinction (Fig. 4B). Lastly, extinction positions become increasingly more difficult to observe as the particles become thinner because the retardation decreases.

Compounding this problem, especially for particles (e.g. tremolite and winchite) resting on the (100) surface, is a decrease in the birefringence of that plane based on the optical orientation of the mineral, because a circular section (isotropic view) of the indicatrix is near parallel to the microscope stage (Fig. 4B). Thus, precautions need to be taken when using extinction data for determining fibers vs. fragments. In this study we have measured the extinction angles for the differing directions for all three of our samples, in order to use these data to help interpret which form the samples have.

Su and Bloss (37) give equations for calculating extinction angles for any (hk0) plane in a monoclinic amphibole based on its optical orientation and 2V, and they warn how extinction angles are often misinterpreted. For instance, it is often assumed that the extinction angle increases from zero for a sample resting on (100) to a maximum when the sample rests on (010). This assumption is not always true (i.e., the maximum "extinction" angle may occur on some (hk0) plane other than (010)). Bandli and Gunter (13) have shown that the Libby samples exhibit (100) and (110) faces. Thus, we expect different extinction angles depending on the face the sample rested on.

The circled crystal in Figure 1A, the UI tremolite sample, is resting on (110) and exhibits inclined extinction in Figure 1B. This sample is in the orientation as shown in the bottom sketch in Figure 4A. In this orientation, the sample has an extinction angle of 13°, which is not the true extinction angle (as measured on (010)) of 16°. Table 5 summarizes the extinction data for all the samples in this study. For the UI tremolite, 99 of the particles rested on (110) and yielded

an extinction angle of 13°, while one fragment rested on (100) and gave parallel extinction. For the NIST tremolite sample in Figure 1D (the circled crystal in 1C), the crystal shows inclined extinction indicating that the sample is resting on its (110) surface. Table 5 shows that 15 of the 99 NIST tremolite fragments were in this orientation, while 22 of them showed parallel extinction. Thus, 59% of the NIST fragments with observable extinction rested on (100), while 1% of the UI tremolite fragments were flattened on (100). These particles were fragments even though they exhibited parallel extinction; they are single crystals based on morphology. Also, note that 12 of the fragment's retardations were too low to observe extinction conditions.

The major difference between the Libby samples and the NIST tremolite is the larger number of "isotropic" particles in the former. For the Libby sample, the optical orientation, and thus extinction angle, differs from the tremolite samples. The extinction angle for the Libby samples is 20°, based on the single particle data in Table 8. Also, these samples have a lower retardation; thus, more "isotropic" particles occur. At first glance, it appears that more of the Libby fragments exhibit inclined extinction than the NIST samples. This would imply that more of the Libby particles rest on (110) than (100). However, this is probably not the case. Assuming that all the "isotropic" particles result from samples resting on (100), then for the NIST sample 29% of the particles rest on (110) and 67% on (100), and for the Libby samples 26% rest on (110) and 70% on (100).

DISCUSSION - SINGLE CRYSTALS

Observations from the photographs in Figures 2 and 3 reveal a trend in the size and shape of the three samples used in the study and the morphological characteristics of the fibers vs. fragments. Figures 2A and 2B show a UI tremolite sample viewed perpendicular to its widest dimension (Fig. 2A) and its thinnest direction (Fig. 2B). Clearly this is a single crystal (parallel sides, blunt ends), and its width to thickness ratio would be high when compared to the single crystal fragments of the NIST tremolite (Figs. 2G and 2H) and the Libby amphibole (Figs. 3G and 3H) viewed in similar orientations. The samples appear similar morphologically, the aspect ratios (l/w) are higher for the NIST and Libby samples, but the width to thickness aspect ratios appear lower. The remaining five sets of photographs are of fibers bundles and masses from the NIST tremolite (Figs. 2C to 2F) and the Libby amphibole (Figs. 3A to 3F). Differences in the morphology can be observed between these fiber bundles and single crystals. It is worth noting these particles were admixed in the deposits, i.e. they occurred together in the rock.

As seen in the photos of the fiber bundles in Figures 2 and 3, some of the samples appear more fibrous when viewed perpendicular to their widest direction (left column in Figures 2, 3). When the samples are rotated 90°, some of them appear much less fibrous (right column in Figures 2, 3). This is especially true in Figures 3D and 3F. A somewhat reverse observation for the NIST tremolite samples occurred. In Table 7, 11 of 25 samples had parallel extinction on the widest section, as would be the case if they were flattened on (100), as shown in Figure 4B. However, when rotated 90° the samples never went extinct, and although they appeared morphologically to be fragments (blunt end, parallel sides), they were fibers. Some of the NIST tremolite particles in grain mounts, that we classified as fragments, are probably fibers. This observation was only possible by rotating the samples and observing them in an orientation that would rarely be seen in a grain mount.

After these initial observations, our goal was to quantify the morphology so that we could calculate aspect ratios and measure extinction conditions for different orientations. The UI tremolite was used as a non-asbestos standard. We mounted 10 samples on a spindle stage in order to measure the thickest direction, corresponding to the width of the particle, and the thinnest direction, corresponding to the thickness of the particle (Table 6). The single crystals were rotated about the spindle axis until these directions were located. Data obtained in this manner are shown in Table 6A. These data show extinction angles that would be measured when the samples were viewed perpendicular, or near so, to (110) for all the samples except #4 and #10, which were viewed perpendicular to their (100) surfaces. The average value for extinction angles measured on the width is 14° which is nearly the same as was found in the grain mounts, 13°. Next, to measure the true extinction angle we repeated the measurements made in Table 6A, except each sample was rotated to place the (010) plane in the microscope stage, yielding an extinction angle of 16° (Table 6B). As was expected, in all cases these samples exhibited parallel extinction when (100) was in the plane of the microscope stage. Regardless of which table one uses, the aspect ratios increase significantly for l/t when compared to l/w.

Table 7 lists data for the 25 particles measured for the NIST tremolite. For the NIST tremolite, the 10 single crystals yielded an extinction of 16°, which differs from the value of 12° in Table 5 for the NIST samples in the grain mount. This is because all of the single crystal particles measured on the spindle stages were flattened on (100), and some of the grain mount samples were on (110). Eleven of the 15 fiber bundles in the NIST sample showed parallel extinction on their widest direction (i.e., how they would rest in a grain mount); this confirms the observations of Wylie (21). However, based on their morphology, we would classify these particles as fragments and explain the parallel extinction by the fact that they rested on (100). As stated above, we only classified these particles as fibers when we rotated them 90° and noted they never went extinct in that orientation. We could also observe a fibrous nature in this orientation that did not exist in the other orientation but only in crossed polars (particle #7, Table 7). The remaining 4 particles never went extinct in any orientation (for example, particle #5, Table 7).

Table 8 gives the individual measurements and observations for the 50 particles of the Libby amphibole vein sample. As was the case for the NIST samples, we classified the Libby samples as either fragments or fibers based on their morphology, but there were two types of fibers in this sample: fiber bundles (e.g., particle #7, Table 8, Figs. 3A and 3B) similar to those in the NIST sample and fiber masses (e.g., particle #18, Table 8, Figs. 3E and 3F). The fiber bundles tended to have parallel extinction regardless of the orientation (i.e., the setting of the spindle stage rotation), while the fiber masses had measurable extinction angles in both the widest and narrowest directions, but the angles do not correspond to any extinction angles. There possibly was a different mode of occurrence for the masses and the bundles; however, all of these particles came from the same sample and should have undergone similar conditions of formation. The fragments yielded an average extinction angle of 20°, which is similar to that obtained from the grain mounts, although there was considerable scatter in the grain mount data.

CONCLUSION

Five amphibole samples were characterized with polarized light microscopy and the spindle stage. They include three amphibole samples from the former vermiculite mine located in Libby, Montana that were collected by the author (MEG) in October, 1999 (Libby amphibole) together with a NIST tremolite-asbestos standard (NIST tremolite) and a non-asbestos tremolite from the University of Idaho teaching collection (UI tremolite). Amphiboles from all of the samples were characterized as standard grain mounts and as single particles using the polarized light microscope and the spindle stage.

The size and morphology were determined for approximately 1000 particles in the grain mounts. Also, the length, width and thickness for 85 single particles were measured with the assistance of the spindle stage. This includes fifty (50) single particles of the Libby amphibole, twenty-five (25) of the NIST tremolite, and ten (10) of the UI tremolite. In addition, extinction angles for different (hk0) planes were measured by adjusting the particles so their crystallographic c-axes were parallel to the rotation axis of the spindle and related to the observations in the grain mounts.

Based on the regulatory counting criteria of asbestos (i.e., an aspect ratio of 3:1 or higher), 95% of the Libby amphibole, 92% of the NIST tremolite, and 48% of the UI tremolite were asbestos. Based on morphology, 36% of the Libby amphibole, 19% of the NIST tremolite, and 0% of the UI tremolite were asbestos.

One of the main goals of this study was to better characterize the Libby samples; no doubt over the next several years many similar studies will be performed. However, to date, there is only one study of the samples at Libby, and it is not in the open literature but rather in an EPA report (36). The study found that 100% of the particles had an aspect ratio greater than 3:1, 88% greater than 10:1, and 52% greater than 20:1. Again, this compares well to our study in which we found 95% greater than 3:1, 73% greater than 10:1, and 49% greater than 20:1.

The application of the spindle stage also made it easier to distinguish between fibers and non-fibrous cleavage fragments. It was found that many of the NIST tremolite particles appearing as fragments in grain mounts appear as fibers upon rotation. Extinction angles were also determined for different (hk0) planes and these data were used to help interpret the observations made on the grain mounts. These observations showed that the non-asbestos samples mainly rested on their (110) surfaces, although the smaller of these were flattened on (100); the small fragments in the NIST tremolite and Libby amphibole were predominantly flattened on (100).

APPENDIX

Table 1. Size Distribution (By Particle) for UI Tremolite, NIST Tremolite, and Libby Amphibole as Determined from Grain Mounts with a PLM

Sample	Width(μm)	Length (μm)				
		0-10	11-20	21-50	51-100	>100
UI tremolite	0-1	0	0	0	0	0
(n=100)	1.1-2	0	0	0	0	0
	2.1-5	0	0	0	0	0
	5.1-10	0	0	1	0	0
	>10	0	0	0	0	99
NIST	0-1	3	0	0	0	0
(n=99)	1.1-2	4	2	6	2	1
	2.1-5	2	7	11	6	1
	5.1-10	1	4	4	9	12
	>10	0	1	3	8	12
Libby outcrop	0-1	0	1	2	2	1
(n=298)	1.1-2	2	5	29	34	12
	2.1-5	1	3	24	45	51
	5.1-10	0	0	7	20	51
	>10	0	0	0	1	7
Libby vein	0-1	21	33	29	12	4
(n=299)	1.1-2	14	19	15	22	16
	2.1-5	6	8	14	13	27
	5.1-10	1	0	9	3	17
	>10	0	1	5	6	4
Libby float	0-1	26	34	48	14	14
(n=300)	1.1-2	18	20	33	10	14
	2.1-5	10	7	9	2	5
	5.1-10	3	6	1	5	2
	>10	0	1	8	2	8

Table 2. Percent of Fibers, Fragments, and Not Classified in the UI Tremolite, NIST Tremolite, and Libby Amphibole Determined Morphologically and Grouped by Aspect Ratio (l/w)

Sample	Aspect Ratio	Fibers(%)	Fragments (%)	Not Classified (%)	Total (%)
UI tremolite	<3	0	52	0	52
	3-5	0	29	0	29
	6-10	0	15	0	15
	11-20	0	4	0	4
	21-50	0	0	0	0
	51-100	0	0	0	0
	>100	0	0	0	0
NIST tremolite	<3	0	7	1	8
	3-5	1	18	7	26
	6-10	3	7	9	19
	11-20	9	14	10	33
	21-50	4	5	1	10
	51-100	2	1	1	4
	>100	0	0	0	0
Libby outcrop	<3	0	0	0	0
	3-5	0	3	0	3
	6-10	2	7	2	11
	11-20	8	8	7	23
	21-50	17	14	12	43
	51-100	7	3	3	13
	>100	3	2	2	7
Libby vein	<3	0	5	0.4	5.4
	3-5	0.4	8	3	11.4
	6-10	1	8	7	16
	11-20	5.5	5	11	21.5
	21-50	12	6	8	26
	51-100	6	2	1	9
	>100	10	0.7	0	10.7
Libby float	<3	0	8	0.7	8.7
	3-5	0	6.5	4	10.5
	6-10	3	4	10	17
	11-20	6	7	11	24
	21-50	12	2	10	24
	51-100	7	0.4	0.7	8.1
	>100	7	0.7	0	7.7

Table 3. Percent of Fibers, Fragments, and Not Classified in the Three Libby Amphibole Samples Combined from Table 2, and Grouped by Aspect Ratio (l/w)

Aspect Ratio	Fibers (%)	Fragments (%)	Not Classified (%)
<3	0	4.3	0.3
3-5	0.1	5.8	2.3
6-10	2	6.3	6.3
11-20	6.5	7	10
21-50	13	7	10
51-100	7	1.8	1.6
>100	7	1.1	0.6

Table 4. Summary of Classification of Fibers, Fragments, and Not Classified for the UI Tremolite, NIST Tremolite, and Libby Amphibole Based on Aspect Ratio and Morphology

	Sample	Fibers (%)	Fragments (%)	Not Classified (%)
A. Aspect Ratio	UI tremolite	48	52	-
	NIST	92	8	-
	outcrop	100	0	-
	vein	95	5	-
	float	91	9	-
	total (Libby)	95	5	-
B. Morphology	UI tremolite	0	100	0
	NIST	19	52	29
	outcrop	37	37	26
	vein	35	35	30
	float	35	29	36
	total (Libby)	36	33	31

Table 5. Summary of Extinction Measurements for UI Tremolite, NIST Tremolite, and Libby Amphibole in Grain Mounts[1]

Sample	Parallel	Inclined	"Isotropic"	Cannot Measure	Total
UI tremolite					
fragments	1	99 / 13°(4)	0	0	100
NIST					
fibers	13	0	6	0	19
fragments	22	15 / 12°(5)	12	2	51
not classified	7	1	21	0	29
total	42	16	39	2	99
Libby					
fibers					
outcrop	45	0	61	1	107
vein	18	0	83	5	106
float	18	0	83	1	102
total	81	0	227	7	315
fragments					
outcrop	16	31 / 27°(13)	73	1	121
vein	2	30 / 21°(8)	67	2	101
float	5	21 / 20°(8)	55	8	89
total	23	82	195	11	311
not classified					
outcrop	11	2	45	12	70
vein	1	0	90	1	92
float	3	0	105	1	109
total	15	2	240	14	271

[1]Entries in the table represent the number of particles in each sample that have the characteristics listed in the column heading. "Isotropic" means the particle's retardation was too low to observe extinctions. "Cannot measure" means the particle never went extinct or had wavy extinction. Also in the inclined column is the average extinction angle with its standard deviation in parentheses.

Table 6. Morphological Measurements Obtained with the Aid of a Spindle for Ten Particles of the UI Tremolite Sample[1]

A. Width (w) and thickness (t) obtained from the widest and thinnest part of the sample; extinction angles (e.a. on w and e.a. on t) were obtained in these same orientations.

Particle	l (μm)	w (μm)	t (μm)	e.a. on w	e.a. on t	l/w	l/t	w/t
1	297	114	34	12°	15°	2.6	8.7	3.4
2	381	149	82	15°	16°	2.6	4.6	1.8
3	437	133	28	12°	17°	3.3	15.6	4.8
4	403	55	27	parallel	15°	7.3	14.9	2.0
5	667	127	98	14°	16°	5.3	6.8	1.3
6	134	96	73	16°	13°	1.4	1.8	1.3
7	442	59	32	16°	11°	7.5	13.8	1.8
8	567	146	106	11°	16°	3.9	5.3	1.4
9	562	120	38	13°	18°	4.7	14.8	3.2
10	852	76	50	parallel	15°	11.2	17.0	1.5

B. Width (w100) and thickness (t010) obtained on (100) and (010) planes; extinction angles (100 e.a. and 010 e.a.) were obtained in these same orientations.

Particle	l (μm)	w100 (μm)	t010 (μm)	100 e.a.	010 e.a.	l/w100	l/t010	w100/t010
1	297	104	42	parallel	17°	2.9	7.1	2.5
2	381	140	85	parallel	17°	2.7	4.5	1.6
3	437	123	71	parallel	17°	3.6	6.2	1.7
4	403	55	27	parallel	15°	7.3	14.9	2.0
5	667	103	93	parallel	14°	6.5	7.2	1.1
6	134	74	74	parallel	17°	1.8	1.8	1.0
7	442	33	44	parallel	16°	13.4	10.0	0.8
8	567	143	81	parallel	17°	4.0	7.0	1.8
9	562	113	32	parallel	16°	5.0	17.6	3.5
10	852	76	50	parallel	15°	11.2	17.0	1.5

[1]All ten particles were fragments based on morphology, while 7 of 10 would be classified as asbestos based on aspect ratio.

Table 7. Morphological Measurements Obtained with the Aid of a Spindle for Twenty-five Particles of the NIST Tremolite Sample[1]

Particle	l (μm)	w (μm)	t (μm)	l/w	l/t	w/t	e.a. on w	e.a. on t	type
1	493	83	54	6	9	1.5	parallel	never	fiber bundle
2	169	8	6	21	28	1.3	parallel	16°	fragment
3	744	88	40	8	19	2.2	parallel	never	fiber bundle
4	709	57	22	12	32	2.6	parallel	never	fiber bundle
5	728	175	78	4	9	2.2	never	never	fiber bundle
6	815	116	84	7	10	1.4	never	never	fiber bundle
7	594	78	39	8	15	2.0	parallel	never	fiber bundle
8	226	16	12	14	19	1.3	parallel	never	fiber bundle
9	435	29	15	15	29	1.9	parallel	17°	fragment
10	756	33	19	23	40	1.7	parallel	13°	fragment
11	1023	71	16	14	64	4.4	parallel	never	fiber bundle
12	644	40	29	16	22	1.4	parallel	never	fiber bundle
13	561	9	5	62	112	1.8	never	never	fiber bundle
14	630	95	67	7	9	1.4	never	never	fiber bundle
15	445	107	52	4	9	2.1	parallel	never	fiber bundle
16	146	32	21	5	7	1.5	parallel	never	fiber bundle
17	536	18	7	30	77	2.6	parallel	16°	fragment
18	875	27	20	32	44	1.4	parallel	16°	fragment
19	521	58	36	9	14	1.6	parallel	18°	fragment
20	473	42	28	11	17	1.5	parallel	17°	fragment
21	302	49	25	6	12	2.0	parallel	15°	fragment
22	602	39	14	15	43	2.8	parallel	never	fiber bundle
23	920	28	20	33	46	1.4	parallel	15°	fragment
24	718	48	18	15	40	2.7	parallel	17°	fragment
25	579	86	35	7	17	2.5	parallel	never	fiber bundle

[1]Width (w) and thickness (t) obtained from the widest and thinnest part of the sample; extinction angles (e.a. on w and e.a. on t) were obtained in these same orientations. Particle "type" determined based on morphological characteristics.

Table 8. Morphological Measurements Obtained with the Aid of a Spindle Stage for Fifty Particles of the Libby Vein Sample[1]

Particle	l (μm)	w (μm)	t (μm)	l/w	l/t	w/t	e.a. on w	e.a. on t	type
1	333	47	21	7	16	2.2	never	22°	fiber bundle
2	530	62	47	9	11	1.3	never	never	fiber mass
3	660	68	42	10	16	1.6	17°	22°	fiber bundle
4	577	122	67	5	9	1.8	parallel	parallel	fiber bundle
5	438	116	64	4	7	1.8	parallel	parallel	fiber bundle
6	654	60	32	11	20	1.9	parallel	parallel	fiber bundle
7	537	99	54	5	10	1.8	parallel	parallel	fiber bundle
8	362	83	63	4	6	1.3	10°	parallel	fiber mass
9	387	53	52	7	7	1.0	15°	10°	fiber bundle
10	321	46	28	7	11	1.6	parallel	19°	fragment
11	428	105	47	4	9	2.2	13°	parallel	fragment
12	492	78	58	6	8	1.3	parallel	parallel	fiber bundle
13	519	77	31	7	17	2.5	9°	parallel	fiber bundle
14	940	157	101	6	9	1.6	parallel	17°	fragment
15	1341	52	31	26	43	1.6	never	never	fiber bundle
16	354	180	162	2	2	1.1	39°	7°	fiber mass
17	541	105	61	5	9	1.7	parallel	parallel	fiber bundle
18	438	141	87	3	5	1.6	14°	13°	fiber mass
19	328	168	85	2	4	2.0	20°	parallel	fiber mass
20	700	73	69	10	10	1.1	parallel	parallel	fragment
21	392	142	66	3	6	2.2	10°	parallel	fragment
22	512	73	55	7	9	1.3	parallel	parallel	fiber bundle
23	316	52	38	6	8	1.4	parallel	parallel	fiber bundle
24	467	28	13	17	36	2.2	7°	parallel	fragment
25	714	73	29	10	25	2.5	parallel	19°	fragment
26	432	91	44	5	10	2.1	parallel	22°	fragment
27	423	70	56	6	8	1.3	22°	18°	fragment
28	591	74	38	8	16	1.9	15°	10°	fiber bundle
29	1460	71	36	21	41	2.0	never	never	fiber bundle
30	481	37	13	13	37	2.8	parallel	23°	fragment
31	764	142	111	5	7	1.3	never	never	fiber mass
32	661	45	28	15	24	1.6	parallel	21°	fragment
33	772	30	24	26	32	1.3	parallel	parallel	fiber bundle
34	542	53	39	10	14	1.4	parallel	parallel	fiber bundle
35	481	35	25	14	19	1.4	parallel	15°	fragment
36	627	57	48	11	13	1.2	20°	parallel	fiber bundle
37	483	26	12	19	40	2.2	parallel	23°	fragment
38	456	36	32	13	14	1.1	parallel	22°	fragment
39	587	29	23	20	26	1.3	parallel	parallel	fiber bundle
40	728	26	12	28	61	2.2	parallel	22°	fragment
41	738	140	103	5	7	1.4	12°	parallel	fiber bundle
42	363	89	81	4	4	1.1	parallel	parallel	fiber bundle
43	309	22	21	14	15	1.0	parallel	parallel	fiber bundle
44	546	74	40	7	14	1.9	parallel	23°	fragment
45	321	10	8	32	40	1.3	parallel	parallel	fiber bundle
46	327	50	44	7	7	1.1	parallel	21°	fragment
47	375	40	24	9	16	1.7	parallel	23°	fragment
48	710	50	34	14	21	1.5	parallel	parallel	fiber bundle
49	497	20	7	25	71	2.9	parallel	16°	fragment
50	703	17	17	41	41	1.0	27°	20°	fiber bundle

[1]Width (w) and thickness (t) obtained from the widest and thinnest part of the sample; extinction angles (e.a. on w and e.a on t) were obtained in these same orientations. Particle "type" determined based on morphological characteristics.

REFERENCES CITED

(1) Selikoff, I.J., Churg, J., and Hammond, E.C. "Asbestos exposure and neoplasia"; *Journal of the American Medical Association* **1984**, 252, 91-95.

(2) Skinner, H.C.W., Ross, M., and Frondel, C. *Asbestos and other fibrous materials; mineralogy, crystal chemistry, and health effects;* Oxford University Press: New York, 1988.

(3) Guthrie, G.D., Jr. and Mossman, B.T. eds. *Reviews in Mineralogy: Health effects of mineral dusts, 28;* Mineralogical Society of America, Washington, D.C. 1993.

(4) Nolan, R.P., Langer, A.M., Ross, M., Wicks, F.J., and Martin, R.F. *The health effects of chrysotile asbestos: contribution of science to risk-management decisions;* Special Publication #5, Mineralogical Association of Canada, Ottawa, 2001.

(5) Ross, M. "The geologic occurrences and health hazards of amphibole and serpentine asbestos"; In *Reviews in Mineralogy: Amphiboles and other hydrous pyriboles-mineralogy;* D.R. Veblen, Ed.; 1981; 9A, 279-323.

(6) Mossman, B.T., Bignon, J., Corn, M., Seaton, A., and Gee, J.B.L. "Asbestos: Scientific developments and implications for public policy"; *Science* **1990**, 247, 294-301.

(7) Gunter, M.E. "Asbestos as a metaphor for teaching risk perception"; *Journal of Geological Education* **1994**, 42, 17-24.

(8) Weill, H., Abraham, J.L., Balmes, J.R., Case, B., Chrug, A., Hughes, J., Schenker, M., and Sebastien, P. "Health effects of tremolite"; *American Review of Respiratory Diseases* **1990**, 142, 1453-1458.

(9) Case, B.W. "Health effects of tremolite"; In *The third wave of asbestos disease: Exposure to asbestos in place;* P.J. Landrigan, H. Kazemi, Eds.; Annals of the New York Academy of Sciences, 1991; 643, 491-504

(10) Nolan, R.P, Langer, A.M., Oechsle, G.W., Addison, J., and Colflesh, D.E. "Association of tremolite habit with biological potential: Preliminary report"; *In Mechanisms in fibre carcinogenesis;* R.C. Brow, J.A. Hoskins, N.F. Johnson, Eds.; 1991; 231-251.

(11) Davis, J.M.G., Addison, J., Bolton, R.E., Donaldson, K., Jones, A.D., and Miller, B.G. "Inhalation studies on the effects of tremolite and brucite dust in rats"; *Carcinogenesis* **1985**, 6, 667-674.

(12) Davis, J.M.G, Addison, J., McIntosh, C., Miller, B.G., and Niven, K. "Variations in the carcinogenicity of tremolite dust samples of differing morphology"; *In The third wave of asbestos disease: Exposure to asbestos in place;* P.J. Landrigan, H. Kazemi, Eds.; Annals of the New York Academy of Sciences, 1991; 643, 473-490.

(13) Bandli, B.R. and Gunter, M.E. " Identification and characterization of mineral and asbestos particles using the spindle stage and the scanning electron microscope: The Libby, Montana, U.S.A. amphibole-asbestos as an example"; *The Microscope* **2001**, 49, 191-199.

(14) Wylie, A.G. and Verkouteren, J.R. "Amphibole asbestos from Libby, Montana: Aspects of nomenclature"; *American Mineralogist* **2000**, 85, 1540-1542.

(15) Gunter, M.E., Dyar, M.D., Twamley, B., Foit, F.F., Jr., and Cornelius, S. "Crystal chemistry and crystal structure of amphibole and amphibole-asbestos from Libby, Montana, U.S.A."; *American Mineralogist* **2003**, 1944-1952.

(16) Wylie, A.G. "Relationship between the growth habit of asbestos and the dimensions of asbestos fibers"; *Mining Engineering* **1988**, 40, 1036-1040.

(17) Wagner, J.C., Chamberlain, M., Brown, R.C., Berry, G., Poley, F.D., Davies, R., and Griffiths, D.M. "Biological effects of tremolite"; *British Journal of Cancer* **1982**, 45, 352-360.

(18) Wylie, A.G., Shedd, K.B., and Taylor, M.E. "Measurement of the thickness of amphibole asbestos fibers with the scanning electron microscope and the transmission electron microscope"; In *Microbeam Analysis;* K. Heinrich, Ed., San Francisco Press, San Francisco, California 1982; 181-187.

(19) Langer, A.M., Nolan, R.P., and Addison, J. "Distinguishing between amphibole asbestos fibers and elongate cleavage fragments of their non-asbestos analogues"; In *Mechanisms in fibre carcinogenesis;* R.C. Brow, J.A. Hoskins, N.F. Johnson, Eds; 1991; 253-267.

(20) Zoltai, T. "Asbestiform and acicular mineral fragments"; In *Health hazards of asbestos exposure*; I.J. Selikoff and E.C. Hammond, Eds.; Annals of the New York Academy of Sciences, 1979; 330, 621-643.

(21) Wylie, A.G. "Optical properties of the fibrous amphiboles"; In *Health hazards of asbestos exposure*; I.J. Selikoff and E.C. Hammond, Eds.; Annals of the New York Academy of Sciences, 1979; 330, 611-619.

(22) Zoltai, T. and Wylie, A.G. "Definitions of asbestos-related mineralogical terminology"; In *Health hazards of asbestos exposure*; I.J. Selikoff, E.C. Hammond, Eds.; Annals of the New York Academy of Sciences ,1979; 330, 707-709.

(23) OSHA "Occupational exposure to asbestos, tremolite, anthophyllite, and actinolite"; *Federal Register* **1992**, 57, 24310.

(24) Zoltai, T. "Amphibole asbestos mineralogy"; In *Reviews in Mineralogy: Amphiboles and other hydrous pyriboles—mineralogy*; D.R. Veblen, Ed.; 1981; 9A, 237-278.

(25) Dorling, M. and Zussman, J. (1987) "Characteristics of asbestiform and non-asbestifrom calcic amphiboles"; *Lithos* **1987**, 20, 469-489.

(26) Veblen, D.R. and Wylie, A.G. "Mineralogy of amphiboles and 1:1 layer silicates"; In *Reviews in Mineralogy: Health effects of mineral dusts*; G.D. Guthrie, Jr., B.T. Mossman Eds.; 1993; 28, 61-138.

(27) Ross, M., Nolan, R.P., Langer, A.M., and Cooper, W.C. "Health effects of mineral dusts other than asbestos"; *In Reviews in Mineralogy: Health effects of mineral dusts*; G.D. Guthrie, Jr. and B.T. Mossman Eds.; 1993; 28, 361-409.

(28) Van Oss, C.J., Naim, J.O., Costanzo, P.M., Giese, R.F., Jr, Wu, W., and Sorling, A.F. "Impact of different asbestos species and other mineral particles on pulmonary pathogenesis"; *Clays and Clay Minerals* **1999**, 47, 697-707.

(29) Gunter, M.E. "Quartz – the most abundant mineral species in the earth's crust and a human carcinogen"; *Journal of Geoscience Education* **1999**, 47, 341-349.

(30) Guthrie, G.D., Jr. "Mineral properties and their contributions to particle toxicity"; *Environmental Health Perspectives* **1997**, 105, 1003-1011.

(31) Guthrie, G.D., Jr. "Mineralogical factors affect the biological activity of crystalline silica"; *Applications to Occupational Environmental Hygiene* **1995**, 10, 1126-1131.

(32) Guthrie, G.D., Jr. "Biological effects of inhaled minerals"; *American Mineralogist* **1992**, 77, 225-243.

(33) Wylie, A.G. and Huggins, C.W. "Characteristics of a potassian winchite-asbestos from the Allamoore Talc District, Texas"; *Canadian Mineralogist* **1980**, 18, 101-107.

(34) Gunter, M.E. and Twamley, B. "A new method to determine the optical orientation of biaxial minerals: A mathematical approach"; *Canadian Mineralogist* **2001**, 39, 1701-1711.

(35) Wylie, A.G. and Schweitzer, P. "The effects of sample preparation and measuring methods on the shape and shape characterization of mineral particles: The case of wollastonite"; *Environmental Research* **1982**, 27, 52-73.

(36) Atkinson, G.R., Rose, D., Thomas, K., Jones, D., Chatfield, E.J., and Going, J.E. "Collection, analysis and characterization of vermiculite samples for fiber content and asbestos contamination"; Reports to EPA 1982, Project 4901-A32, Contract No. 68-01-5915.

(37) Su, S.C. and Bloss, F.D. "Extinction angles for monoclinic amphiboles and pyroxenes: a cautionary note"; *American Mineralogist* **1984**, 69, 399-403.

ATTACHMENT 7

POLARIZED LIGHT MICROSCOPY OF ASBESTOS

Method number:	ID-191
Matrix:	Bulk
OSHA Content Limit:	0.1%
Collection Procedure:	Collect approximately 1 to 2 grams of each type of material and place into separate 20 mL scintillation vials.
Analytical Procedure:	A portion of each separate phase is analyzed by gross examination, phase-polar examination, and central stop dispersion microscopy.
Detection Limit:	Less than 1% by area.
Special Requirements:	Send bulk samples to the laboratory in separate packages from air samples.
Physical Scientist:	Daniel T. Crane
Date:	21 October 1992, (December 1992)

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1. Introduction

This method describes the collection and analysis of asbestos bulk materials by light microscopy techniques including phase-polar illumination and central-stop dispersion microscopy. Some terms unique to asbestos analysis are defined below:

phibole: A family of minerals whose crystals are formed by long, thin units which have two thin ribbons of uble chain silicate with a brucite ribbon in between. The shape of each unit is similar to an "I beam". Minerals important in asbestos analysis include cummingtonite-grunerite, crocidolite, tremolite-actinolite and anthophyllite.

Asbestos: A term for naturally occurring fibrous minerals. Asbestos includes chrysotile, cummingtonite-grunerite asbestos (amosite), anthophyllite asbestos, tremolite asbestos, crocidolite, actinolite asbestos and any of these minerals which have been chemically treated or altered. The precise chemical formulation of each species varies with

the location from which it was mined. Nominal compositions are listed:

Chrysotile	$Mg_3Si_2O_5(OH)_4$
Crocidolite (Riebeckite asbestos)	$Na_2Fe_3^{2+}Fe_2^{3+}Si_8O_{22}(OH)_2$
Cummingtonite-Grunerite asbestos (Amosite)	$(Mg,Fe)_7Si_8O_{22}(OH)_2$
Tremolite-Actinolite asbestos	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
Anthophyllite asbestos	$(Mg,Fe)_7Si_8O_{22}(OH)_2$

Asbestos Fiber: A fiber of asbestos meeting the criteria for a fiber. (see Section 3.5.)

Aspect Ratio: The ratio of the length of a fiber to its diameter usually defined as "length : width", e.g. 3:1.

Brucite: A sheet mineral with the composition $Mg(OH)_2$.

Central Stop Dispersion Staining (microscope): This is a dark field microscope technique that images particles using only light refracted by the particle, excluding light that travels through the particle unrefracted. This is usually accomplished with a McCrone objective or other arrangement which places a circular stop with apparent aperture equal to the objective aperture in the back focal plane of the microscope.

Cleavage Fragments: Mineral particles formed by the comminution of minerals, especially those characterized by relatively parallel sides and moderate aspect ratio.

Differential Counting: The term applied to the practice of excluding certain kinds of fibers from a phase contrast asbestos count because they are not asbestos.

Fiber: A particle longer than or equal to 5 μm with a length to width ratio greater than or equal to 3:1. This may include cleavage fragments. (see Section 3.5.)

Phase Contrast: Contrast obtained in the microscope by causing light scattered by small particles to destructively interfere with unscattered light, thereby enhancing the visibility of very small particles and particles with very low intrinsic contrast.

Phase Contrast Microscope: A microscope configured with a phase mask pair to create phase contrast. The technique which uses this is called Phase Contrast Microscopy (PCM).

Phase-Polar Analysis: This is the use of polarized light in a phase contrast microscope. It is used to see the same size fibers that are visible in air filter analysis (5.1.). Although fibers finer than 1 μm are visible, analysis of these is inferred from analysis of larger bundles that are usually present.

Phase-Polar Microscope: The phase-polar microscope is a phase contrast microscope which has an analyzer, a polarizer, a first order red plate and a rotating phase condenser all in place so that the polarized light image is enhanced by phase contrast.

Sealing Encapsulant: This is a product which can be applied, preferably by spraying, onto an asbestos surface which will seal the surface so that fibers cannot be released.

Serpentine: A mineral family consisting of minerals with the general composition $Mg_3(Si_2O_5(OH)_4$ having the magnesium in brucite layer over a silicate layer. Minerals important in asbestos analysis included in this family are chrysotile, lizardite, antigorite.

1.1. History

Light microscopy has been used for well over 100 years for the determination of mineral species. This analysis is carried out using specialized polarizing microscopes as well as bright field microscopes (5.2.). The identification of minerals is an on-going process with many new minerals described each year. The first recorded use of asbestos was in Finland about 2500 B.C. where the material was used in the mud wattle for the wooden huts the people lived in as well as strengthening for pottery (5.3.). Adverse health aspects of the mineral were noted nearly 2000 years ago when Pliny the Younger wrote about the poor health of slaves in the asbestos mines. Although known to be injurious for centuries, the first modern references to its toxicity were by the British Labor Inspectorate when it banned asbestos dust from the workplace in 1898 (5.4.). Asbestosis cases were described in the literature after the turn of the century. Cancer was first suspected in the mid 1930's and a causal link to mesothelioma was made in 1965 (5.5.). Because of the public concern for worker and public safety with the use of this material, several different types of analysis were applied to the determination of asbestos content. Light microscopy requires a great deal of experience and craft. Attempts were made to apply less subjective methods to the analysis. X-ray diffraction was partially successful in

determining the mineral types but was unable to separate out the fibrous portions from the non-fibrous portions. Also, the minimum detection limit for asbestos analysis by X-ray diffraction (XRD) is about 1%. Differential Thermal Analysis (DTA) was no more successful. These provide useful corroborating information when the presence of asbestos has been shown by microscopy; however, neither can determine the difference between fibrous and non-fibrous minerals when both habits are present. The same is true of Infrared Absorption (IR).

When electron microscopy was applied to asbestos analysis, hundreds of fibers were discovered present too small to be visible in any light microscope. There are two different types of electron microscope used for asbestos analysis: Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM). Scanning Electron Microscopy is useful in identifying minerals. The SEM can provide two of the three pieces of information required to identify fibers by electron microscopy: morphology and chemistry. The third is structure as determined by Selected Area Electron Diffraction - SAED which is performed in the TEM. Although the resolution of the SEM is sufficient for very fine fibers to be seen, accuracy of chemical analysis that can be performed on the fibers varies with fiber diameter in fibers of less than 0.2 μm diameter (5.6.). The TEM is a powerful tool to identify fibers too small to be resolved by light microscopy and should be used in conjunction with this method when necessary. The TEM can provide all three pieces of information required for fiber identification. Most fibers thicker than 1 μm can adequately be defined in the light microscope. The light microscope remains as the best instrument for the determination of mineral type. This is because the minerals under investigation were first described analytically with the light microscope. It is inexpensive and gives positive identification for most samples analyzed. Further, when optical techniques are inadequate, there is ample indication that alternative techniques should be used for complete identification of the sample.

1.2. Principle

Minerals consist of atoms that may be arranged in random order or in a regular arrangement. Amorphous materials have atoms in random order while crystalline materials have long range order. Many materials are transparent to light, at least for small particles or for thin sections. The properties of these materials can be investigated by the effect that the material has on light passing through it. The six asbestos minerals are all crystalline with particular properties that have been identified and cataloged. These six minerals are anisotropic. They have a regular array of atoms, but the arrangement is not the same in all directions. Each major direction of the crystal presents a different regularity. Light photons travelling in each of these main directions will encounter different electrical neighborhoods, affecting the path and time of travel. The techniques outlined in this method use the fact that light traveling through fibers or crystals in different directions will behave differently, but predictably. The behavior of the light as it travels through a crystal can be measured and compared with known or determined values to identify the mineral species. Usually, Polarized Light Microscopy (PLM) is performed with strain-free objectives on a bright-field microscope platform. This would limit the resolution of the microscope to about 0.4 μm. Because OSHA requires the counting and identification of fibers visible in phase contrast (5.7.), the phase contrast platform is used to visualize the fibers with the polarizing elements added into the light path. Polarized light methods cannot identify fibers finer than about 1μm in diameter even though they are visible. The finest fibers are usually identified by inference from the presence of larger, identifiable fiber bundles. When fibers are present, but not identifiable by light microscopy, use either SEM or TEM to determine the fiber identity.

1.3. Advantages and Disadvantages

The advantages of light microcopy are:

a. Basic identification of the materials was first performed by light microscopy and gross analysis. This provides a large base of published information against which to check analysis and analytical technique.

b. The analysis is specific to fibers. The minerals present can exist in asbestiform, fibrous, prismatic, or massive varieties all at the same time. Therefore, bulk methods of analysis such as X-ray diffraction, IR analysis, DTA, etc. are inappropriate where the material is not known to be fibrous.

c. The analysis is quick, requires little preparation time, and can be performed on-site if a suitably equipped microscope is available.

The disadvantages are:

a. Even using phase-polar illumination, not all the fibers present may be seen. This is a problem for very low asbestos concentrations where agglomerations or large bundles of fibers may not be present to allow identification by inference.

b. The method requires a great degree of sophistication on the part of the microscopist. An analyst is only as useful as his mental catalog of images. Therefore, a microscopist's accuracy is enhanced by experience. The mineralogical training of the analyst is very important. It is the basis on which subjective decisions are made.

c. The method uses only a tiny amount of material for analysis. This may lead to sampling bias and

false results (high or low). This is especially true if the sample is severely inhomogeneous.

d. Fibers may be bound in a matrix and not distinguishable as fibers so identification cannot be made.

1.4. Method Performance

1.4.1. This method can be used for determination of asbestos content from 0 to 100% asbestos. The detection limit has not been adequately determined, although for selected samples, the limit is very low, depending on the number of particles examined. For mostly homogeneous, finely divided samples, with no difficult fibrous interferences, the detection limit is below 1%. For inhomogeneous samples (most samples), the detection limit remains undefined. NIST has conducted proficiency testing of laboratories on a national scale. Although each round is reported statistically with an average, control limits, etc., the results indicate a difficulty in establishing precision especially in the low concentration range. It is suspected that there is significant bias in the low range especially near 1%. EPA tried to remedy this by requiring a mandatory point counting scheme for samples less than 10%. (5.8.) The point counting procedure is tedious, and may introduce significant biases of its own. It has not been incorporated into this method.

1.4.2. The precision and accuracy of the quantitation tests performed in this method are unknown. Concentrations are easier to determine in commercial products where asbestos was deliberately added because the amount is usually more than a few percent. An analyst's results can be "calibrated" against the known amounts added by the manufacturer. For geological samples, the degree of homogeneity affects the precision.

1.4.3. The performance of the method is analyst dependent. The analyst must choose carefully and not necessarily randomly the portions for analysis to assure that detection of asbestos occurs when it is present. For this reason, the analyst must have adequate training in sample preparation, and experience in the location and identification of asbestos in samples. This is usually accomplished through substantial on-the-job training as well as formal education in mineralogy and microscopy.

1.5. Interferences

Any material which is long, thin, and small enough to be viewed under the microscope can be considered an interference for asbestos. There are literally hundreds of interferences in workplaces. The techniques described in this method are normally sufficient to eliminate the interferences. An analyst's success in eliminating the interferences depends on proper training.

Asbestos minerals belong to two mineral families: the serpentines and the amphiboles. In the serpentine family, the only common fibrous mineral is chrysotile. Occasionally, the mineral antigorite occurs in a fibril habit with morphology similar to the amphiboles. The amphibole minerals consist of a score of different minerals of which only five are regulated by federal standard: amosite, crocidolite, anthophyllite asbestos, tremolite asbestos and actinolite asbestos. These are the only amphibole minerals that have been commercially exploited for their fibrous properties; however, the rest can and do occur occasionally in asbestiform habit.

In addition to the related mineral interferences, other minerals common in building material may present a problem for some microscopists: gypsum, anhydrite, brucite, quartz fibers, talc fibers or ribbons, wollastonite, perlite, attapulgite, etc. Other fibrous materials commonly present in workplaces are: fiberglass, mineral wool, ceramic wool, refractory ceramic fibers, kevlar, nomex, synthetic fibers, graphite or carbon fibers, cellulose (paper or wood) fibers, metal fibers, etc.

Matrix embedding material can sometimes be a negative interference. The analyst may not be able to easily extract the fibers from the matrix in order to use the method. Where possible, remove the matrix before the analysis, taking careful note of the loss of weight. Some common matrix materials are: vinyl, rubber, tar, paint, plant fiber, cement, and epoxy. A further negative interference is that the asbestos fibers themselves may be either too small to be seen in Phase contrast Microscopy (PCM) or of a very low fibrous quality, having the appearance of plant fibers. The analyst's ability to deal with these materials increases with experience.

1.6. Uses and Occupational Exposure

Asbestos is ubiquitous in the environment. More than 40% of the land area of the United States is composed of minerals which may contain asbestos (5.9.). Fortunately, the actual formation of great amounts of asbestos is relatively rare. Nonetheless, there are locations in which environmental exposure can be severe such as in the Serpentine Hills of California.

There are thousands of uses for asbestos in industry and the home. Asbestos abatement workers are the most current segment of the population to have occupational exposure to great amounts of asbestos. If the material is undisturbed, there is no exposure. Exposure occurs when the asbestos-containing material is abraded or otherwise disturbed during maintenance operations or some other activity. Approximately 95% of the asbestos in place in the United States is chrysotile.

Amosite and crocidolite make up nearly all the difference. Tremolite and anthophyllite make up a very small percentage. Tremolite is found in extremely small amounts in certain chrysotile deposits. Actinolite exposure is probably greatest from environmental sources, but has been identified in vermiculite containing, sprayed-on insulating materials which may have been certified as asbestos-free.

1.7. Physical and Chemical Properties

The nominal chemical compositions for the asbestos minerals were given in Section 1. Compared to cleavage fragments of the same minerals, asbestiform fibers possess a high tensile strength along the fiber axis. They are chemically inert, non-combustible, and heat resistant. Except for chrysotile, they are insoluble in Hydrochloric acid (HCl). Chrysotile is slightly soluble in HCl. Asbestos has high electrical resistance and good sound absorbing characteristics. It can be woven into cables, fabrics or other textiles, or matted into papers, felts, and mats.

1.8. Toxicology (this section is for information only and should not be taken as OSHA policy)

Possible physiologic results of respiratory exposure to asbestos are mesothelioma of the pleura or peritoneum, interstitial fibrosis, asbestosis, pneumoconiosis, or respiratory cancer. The possible consequences of asbestos exposure are detailed in the NIOSH Criteria Document (5.11.) or in the OSHA Asbestos Standards 29 CFR 1910.1001 and 29 CFR 1926.58 (5.7.).

2. Sampling procedure

2.1. Equipment for sampling

a. Tube or cork borer sampling device
b. Knife
c. 20 mL scintillation vial or similar vial
d. Sealing encapsulant

2.2. Safety Precautions

Asbestos is a known carcinogen. Take care when sampling. While in an asbestos-containing atmosphere, a properly selected and fit-tested respirator should be worn. Take samples in a manner to cause the least amount of dust. Follow these general guidelines:

a. Do not make unnecessary dust.
b. Take only a small amount (1 to 2 g).
c. Tightly close the sample container.
d. Use encapsulant to seal the spot where the sample was taken, if necessary.

2.3. Sampling procedure

Samples of any suspect material should be taken from an inconspicuous place. Where the material is to remain, seal the sampling wound with an encapsulant to eliminate the potential for exposure from the sample site. Microscopy requires only a few milligrams of material. The amount that will fill a 20 mL scintillation vial is more than adequate. Be sure to collect samples from all layers and phases of material. If possible, make separate samples of each different phase of the material. This will aid in determining the actual hazard. **DO NOT USE ENVELOPES, PLASTIC OR PAPER BAGS OF ANY KIND TO COLLECT SAMPLES.** The use of plastic bags presents a contamination hazard to laboratory personnel and to other samples. When these containers are opened, a bellows effect blows fibers out of the container onto everything, including the person opening the container.

If a cork-borer type sampler is available, push the tube through the material all the way, so that all layers of material are sampled. Some samplers are intended to be disposable. These should be capped and sent to the laboratory. If a non-disposable cork borer is used, empty the contents into a scintillation vial and send to the laboratory. Vigorously and completely clean the cork borer between samples.

2.4. Shipment

Samples packed in glass vials must not touch or they might break in shipment.

a. Seal the samples with a sample seal (such as the OSHA 21) over the end to guard against tampering and to identify the sample.

b. Package the bulk samples in separate packages from the air samples. They may cross-contaminate each other and will invalidate the results of the air samples.

c. Include identifying paperwork *with* the samples, but not in contact with the suspected asbestos.

d. To maintain sample accountability, ship the samples by certified mail, overnight express, or hand carry them to the laboratory.

3. Analysis

The analysis of asbestos samples can be divided into two major parts: sample preparation and microscopy. Because of the different asbestos uses that may be encountered by the analyst, each sample may need different preparation steps. The choices are outlined below. There are several different tests that are performed to identify the asbestos species and determine the percentage. They will be explained below.

3.1. Safety

a. Do not create unnecessary dust. Handle the samples in HEPA-filter equipped hoods. If samples are received in bags, envelopes or other inappropriate container, open them only in a hood having a face velocity at or greater than 100 fpm. Transfer a small amount to a scintillation vial and only handle the smaller amount.

b. Open samples in a hood, never in the open lab area.

c. Index of refraction oils can be toxic. Take care not to get this material on the skin. Wash immediately with soap and water if this happens.

d. Samples that have been heated in the muffle furnace or the drying oven may be hot. Handle them with tongs until they are cool enough to handle.

e. Some of the solvents used, such as THF (tetrahydrofuran), are toxic and should only be handled in an appropriate fume hood and according to instructions given in the Material Safety Data Sheet (MSDS).

PHASE - POLAR MICROSCOPE

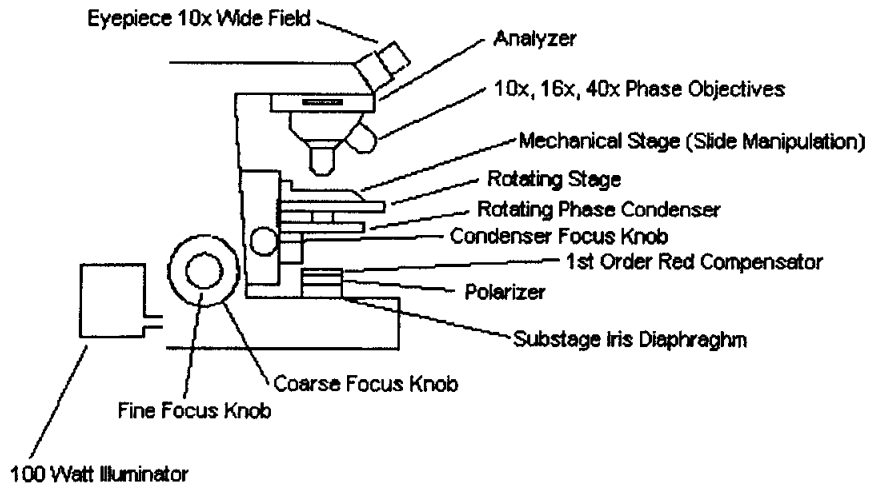


Figure 1:
Phase-Polar Microscope showing the major necessary components

3.2. Equipment

a. Phase contrast microscope with 10×, 16× and 40× objectives, 10× wide-field eyepieces, G-22 Walton-Beckett graticule, Whipple disk, polarizer, analyzer and first order red or gypsum plate, 100 Watt illuminator, rotating position condenser with oversize phase rings, central stop dispersion objective, Kohler illumination and a rotating mechanical stage. (See Figure 1).
b. Stereo microscope with reflected light illumination, transmitted light illumination, polarizer, analyzer and first order red or gypsum plate, and rotating stage.
c. Negative pressure hood for the stereo microscope
d. Muffle furnace capable of 600°C

e. Drying oven capable of 50 - 150°C
f. Aluminum specimen pans
g. Tongs for handling samples in the furnace
h. High dispersion index of refraction oils (Special for dispersion staining.)

n = 1.550
n = 1.585
n = 1.590
n = 1.605
n = 1.620
n = 1.670
n = 1.680
n = 1.690

i. A set of index of refraction oils from about n = 1.350 to n = 2.000 in n = 0.005 increments. (Standard for Becke line analysis.)
j. Glass slides with painted or frosted ends 1 x 3 inches 1 mm thick, precleaned.
k. Cover Slips 22 x 22 mm, #1 1/2
l. Paper clips or dissection needles
m. Hand grinder
n. Scalpel with both #10 and #11 blades
o. 0.1 molar HCl
p. Decalcifying solution (Baxter Scientific Products)

Ethylenediaminetetraacetic Acid, Tetrasodium	0.7 g/liter
Sodium Potassium Tartrate	8.0 mg/liter
Hydrochloric Acid	99.2 g/liter
Sodium Tartrate	0.14 g/liter

q. Tetrahydrofuran (THF)
r. Hotplate capable of 60°C
s. Balance
t. Hacksaw blade
u. Ruby mortar and pestle

3.3. Sample Pre-Preparation

Sample preparation begins with pre-preparation which may include chemical reduction of the matrix, heating the sample to dryness or heating in the muffle furnace. The end result is a sample which has been reduced to a powder that is sufficiently fine to fit under the cover slip. Analyze different phases of samples separately, e.g., tile and the tile mastic should be analyzed separately as the mastic may contain asbestos while the tile may not.

a. ***Wet samples***

Samples with a high water content will not give the proper dispersion colors and must be dried prior to sample mounting. Remove the lid of the scintillation vial, place the bottle in the drying oven and heat at 100°C to dryness (usually about 2 h). Samples which are not submitted to the lab in glass must be removed and placed in glass vials or aluminum weighing pans before placing them in the drying oven.

b. ***Samples with organic interference -- muffle furnace***

These may include samples with tar as a matrix, vinyl asbestos tile, or any other organic that can be reduced by heating. Remove the sample from the vial and weigh in a balance to determine the weight of the submitted portion. Place the sample in a muffle furnace at 500°C for 1 to 2 h or until all obvious organic material has been removed. Retrieve, cool and weigh again to determine the weight loss on ignition. This is necessary to determine the asbestos content of the submitted sample, because the analyst will be looking at a reduced sample.

Note: Heating above 600°C will cause the sample to undergo a structural change which, given sufficient time, will convert the chrysotile to forsterite. Heating even at lower temperatures for 1 to 2 h may have a measurable effect on the optical properties of the minerals. If the analyst is unsure of what to expect, a sample of standard asbestos should be heated to the same temperature for the same length of time so that it can be examined for the proper interpretation.

c. ***Samples with organic interference -- THF***

Vinyl asbestos tile is the most common material treated with this solvent, although, substances containing tar will sometimes yield to this treatment. Select a portion of the material and then grind

it up if possible. Weigh the sample and place it in a test tube. Add sufficient THF to dissolve the organic matrix. This is usually about 4 to 5 mL. **Remember, THF is highly flammable.** Filter the remaining material through a tared silver membrane, dry and weigh to determine how much is left after the solvent extraction. Further process the sample to remove carbonate or mount directly.

d. ***Samples with carbonate interference***

Carbonate material is often found on fibers and sometimes must be removed in order to perform dispersion microscopy. Weigh out a portion of the material and place it in a test tube. Add a sufficient amount of 0.1 M HCl or decalcifying solution in the tube to react all the carbonate as evidenced by gas formation; i.e., when the gas bubbles stop, add a little more solution. If no more gas forms, the reaction is complete. Filter the material out through a tared silver membrane, dry and weigh to determine the weight lost.

3.4. Sample Preparation

Samples must be prepared so that accurate determination can be made of the asbestos type and amount present. The following steps are carried out in the low-flow hood (a low-flow hood has less than 50 fpm flow):

1. If the sample has large lumps, is hard, or cannot be made to lie under a cover slip, the grain size must be reduced. Place a small amount between two slides and grind the material between them or grind a small amount in a clean mortar and pestle. The choice of whether to use an alumina, ruby, or diamond mortar depends on the hardness of the material. Impact damage can alter the asbestos mineral if too much mechanical shock occurs. (Freezer mills can completely destroy the observable crystallinity of asbestos and should not be used). For some samples, a portion of material can be shaved off with a scalpel, ground off with a hand grinder or hack saw blade.

   The preparation tools should either be disposable or cleaned thoroughly. Use vigorous scrubbing to loosen the fibers during the washing. Rinse the implements with copious amounts of water and air-dry in a dust-free environment.

2. If the sample is powder or has been reduced as in 1) above, it is ready to mount. Place a glass slide on a piece of optical tissue and write the identification on the painted or frosted end. Place two drops of index of refraction medium n = 1.550 on the slide. (The medium n = 1.550 is chosen because it is the matching index for chrysotile. Dip the end of a clean paper-clip or dissecting needle into the droplet of refraction medium *on the slide* to moisten it. Then dip the probe into the powder sample. Transfer what sticks on the probe to the slide. The material on the end of the probe should have a diameter of about 3 μm for a good mount. If the material is very fine, less sample may be appropriate. For non-powder samples such as fiber mats, forceps should be used to transfer a small amount of material to the slide. Stir the material in the medium on the slide, spreading it out and making the preparation as uniform as possible. Place a cover-slip on the preparation by gently lowering onto the slide and allowing it to fall "trapdoor" fashion on the preparation to push out any bubbles. Press gently on the cover slip to even out the distribution of particulate on the slide. If there is insufficient mounting oil on the slide, one or two drops may be placed near the edge of the cover slip on the slide. Capillary action will draw the necessary amount of liquid into the preparation. Remove excess oil with the point of a laboratory wiper.

   Treat at least two different areas of each phase in this fashion. Choose representative areas of the sample. It may be useful to select particular areas or fibers for analysis. This is useful to identify asbestos in severely inhomogeneous samples.

   When it is determined that amphiboles may be present, repeat the above process using the appropriate high-dispersion oils until an identification is made or all six asbestos minerals have been ruled out. Note that percent determination must be done in the index medium 1.550 because amphiboles tend to disappear in their matching mediums.

3.5. Analytical procedure

Note: This method presumes some knowledge of mineralogy and optical petrography.

The analysis consists of three parts: The determination of whether there is asbestos present, what type is present and the determination of how much is present. The general flow of the analysis is:

1. Gross examination.
2. Examination under polarized light on the stereo microscope.
3. Examination by phase-polar illumination on the compound phase microscope.
4. Determination of species by dispersion stain. Examination by Becke line analysis may also be used; however, this is usually more cumbersome for asbestos determination.
5. Difficult samples may need to be analyzed by SEM or TEM, or the results from those techniques combined with light microscopy for a definitive identification.

Identification of a particle as asbestos requires that it be asbestiform. Description of particles should follow the suggestion of Campbell (5.6.). (Figure 2)

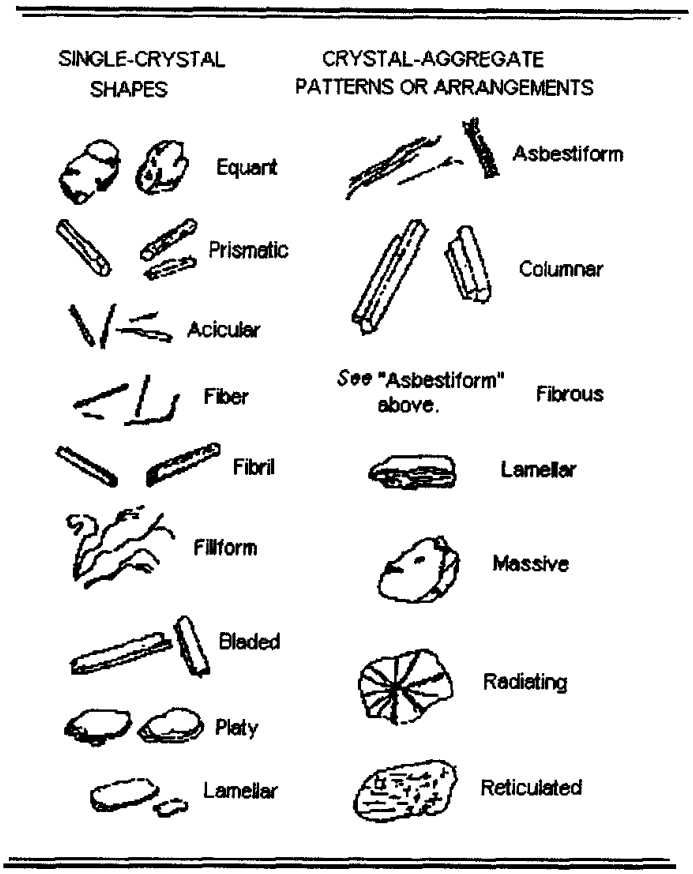


Figure 2:
Particle definitions showing mineral growth habits. From US Bureau of Mines (5.6.).

For the purpose of regulation, the mineral must be one of the six minerals covered and must be in the asbestos growth habit. Large specimen samples of asbestos generally have the gross appearance of wood. Fibers are easily parted from it. Asbestos fibers are very long compared with their widths. The fibers have a very high tensile strength as demonstrated by bending without breaking. Asbestos fibers exist in bundles that are easily parted, show longitudinal fine structure and may be tufted at the ends showing "bundle of sticks" morphology. In the microscope some of these properties may not be observable. Amphiboles do not always show striations along their length even when they are asbestos. Neither will they always show tufting. They generally do not show a curved nature except for very long fibers. Asbestos and asbestiform minerals are usually characterized in groups by extremely high aspect ratios (greater than 100:1). While aspect ratio analysis is useful for characterizing populations of fibers, it cannot be used to identify individual fibers of intermediate to short aspect ratio. Observation of many fibers is often necessary to determine whether a sample consists of "cleavage fragments" or of asbestos fibers.

Most cleavage fragments of the asbestos minerals are easily distinguishable from true asbestos fibers. This is because true cleavage fragments usually have larger diameters than 1 μm. Internal structure of particles larger than this usually shows them to have no internal fibrillar structure. In addition, cleavage fragments of the monoclinic amphiboles show inclined extinction under crossed polars with no compensator. Asbestos fibers usually show extinction at zero degrees or ambiguous extinction if any at all. Morphologically, the larger cleavage fragments are obvious by their blunt or stepped ends showing prismatic habit. Also, they tend to be acicular rather than filiform.

Where the particles are less than 1 μm in diameter and have an aspect ratio greater than or equal to 3:1, it is recommended that the sample be analyzed by SEM or TEM if there is any question whether the fibers are cleavage fragments or asbestiform particles.

Care must be taken when analyzing by electron microscopy because the interferences are different from those in light microscopy and may structurally be very similar to asbestos. The classic interference is between anthophyllite and biopyribole or intermediate fiber. Use the same morphological clues for electron microscopy as are used for light microscopy, e.g. fibril splitting, internal longitudinal striation, fraying, curvature, etc.

1. Gross examination:

   Examine the sample, preferably in the glass vial. Determine the presence of any obvious fibrous component. Estimate a percentage based on previous experience and current observation. Determine whether any pre-preparation is necessary. Determine the number of phases present. This step may be carried out or augmented by observation at 6 to 40× under a stereo microscope.

2. After performing any necessary pre-preparation, prepare slides of each phase as described above. Two preparations of the same phase in the same index medium can be made side-by-side on the same glass for convenience. Examine with the polarizing stereo microscope. Estimate the percentage of asbestos based on the amount of birefringent fiber present.

3. Examine the slides on the phase-polar microscopes at magnifications of 160 and 400×. Note the morphology of the fibers. Long, thin, very straight fibers with little curvature are indicative of fibers from the amphibole family. Curved, wavy fibers are usually indicative of chrysotile. Estimate the percentage of asbestos on the phase-polar microscope under conditions of crossed polars and a gypsum plate. Fibers smaller than 1.0 μm in thickness must be identified by inference to the presence of larger, identifiable fibers and morphology. If no larger fibers are visible, electron microscopy should be performed. At this point, only a tentative identification can be made. Full identification must be made with dispersion microscopy. Details of the tests are included in the appendices.

4. Once fibers have been determined to be present, they must be identified. Adjust the microscope for dispersion mode and observe the fibers. The microscope has a rotating stage, one polarizing element, and a system for generating dark-field dispersion microscopy (see Section 4.6.). Align a fiber with its length parallel to the polarizer and note the color of the Becke lines. Rotate the stage to bring the fiber length perpendicular to the polarizer and note the color. Repeat this process for every fiber or fiber bundle examined. The colors must be consistent with the colors generated by standard asbestos reference materials for a positive identification. In n = 1.550, amphiboles will generally show a yellow to straw-yellow color indicating that the fiber indices of refraction are higher than the liquid. If long, thin fibers are noted and the colors are yellow, prepare further slides as above in the suggested matching liquids listed below:

Type of asbestos	Index of refraction
Chrysotile	n = 1.550
Amosite	n = 1.670 or 1.680
Crocidolite	n = 1.690
Anthophyllite	n = 1.605 and 1.620
Tremolite	n = 1.605 and 1.620
Actinolite	n = 1.620

   Where more than one liquid is suggested, the first is preferred; however, in some cases this liquid will not give good dispersion color. Take care to avoid interferences in the other liquid; e.g., wollastonite in n = 1.620 will give the same colors as tremolite. In n = 1.605 wollastonite will appear yellow in all directions. Wollastonite may be determined under crossed polars as it will change from blue to yellow as it is rotated along its fiber axis by tapping on the cover slip. Asbestos minerals will not change in this way.

   Determination of the angle of extinction may, when present, aid in the determination of anthophyllite from tremolite. True asbestos fibers usually have 0° extinction or ambiguous extinction, while cleavage fragments have more definite extinction.

   Continue analysis until both preparations have been examined and all present species of asbestos are identified. If there are no fibers present, or there is less than 0.1% present, end the analysis with the minimum number of slides (2).

5. Some fibers have a coating on them which makes dispersion microscopy very difficult or impossible. Becke line analysis or electron microscopy may be performed in those cases. Determine the percentage by light microscopy. TEM analysis tends to overestimate the actual percentage present.

6. Percentage determination is an estimate of occluded area, tempered by gross observation. Gross observation information is used to make sure that the high magnification microscopy does not greatly over- or under-estimate the amount of fiber present. This part of the analysis requires a great deal of experience. Satisfactory models for asbestos content analysis have not yet been developed, although some models based on metallurgical grain-size determination have found some utility. (5.13.)

Estimation is more easily handled in situations where the grain sizes visible at about 160× are about the same and the sample is relatively homogeneous.

View all of the area under the cover slip to make the percentage determination. View the fields while moving the stage, paying attention to the clumps of material. These are not usually the best areas to perform dispersion microscopy because of the interference from other materials. But, they are the areas most likely to represent the accurate percentage in the sample. Small amounts of asbestos require slower scanning and more frequent analysis of individual fields.

Report the area occluded by asbestos as the concentration. This estimate does not generally take into consideration the difference in density of the different species present in the sample. For most samples this is adequate. Simulation studies with similar materials must be carried out to apply microvisual estimation for that purpose and is beyond the scope of this procedure.

7. Where successive concentrations have been made by chemical or physical means, the amount reported is the percentage of the material in the "as submitted" or original state. The percentage determined by microscopy is multiplied by the fractions remaining after pre-preparation steps to give the percentage in the original sample. For example:

   Step 1. 60% remains after heating at 550°C for 1 h.
   Step 2. 30% of the residue of step 1 remains after dissolution of carbonate in 0.1 m HCl.
   Step 3. Microvisual estimation determines that 5% of the sample is chrysotile asbestos.

   The reported result is:

   R = (Microvisual result in percent) × (Fraction remaining after step 2) × (Fraction remaining of original sample after step 1)

   $$R = (5) \times (.30) \times (.60) = 0.9\%$$

8. Report the percent and type of asbestos present. For samples where asbestos was identified, but is less than 0.1%, report "Asbestos present, less than 0.1%." There must have been at least two observed fibers or fiber bundles in the two preparations to be reported as present. For samples where asbestos was not seen, report as "None Detected."

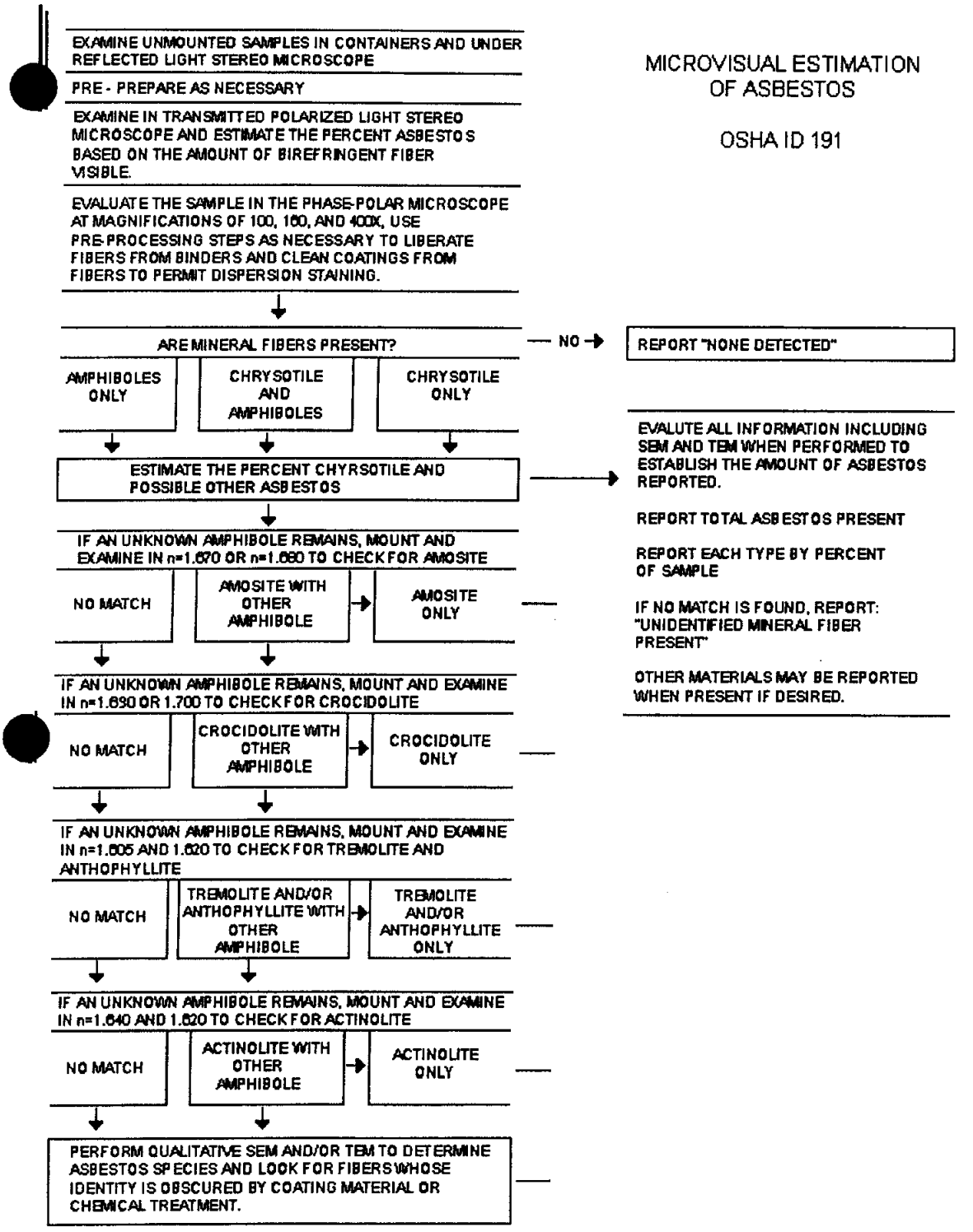


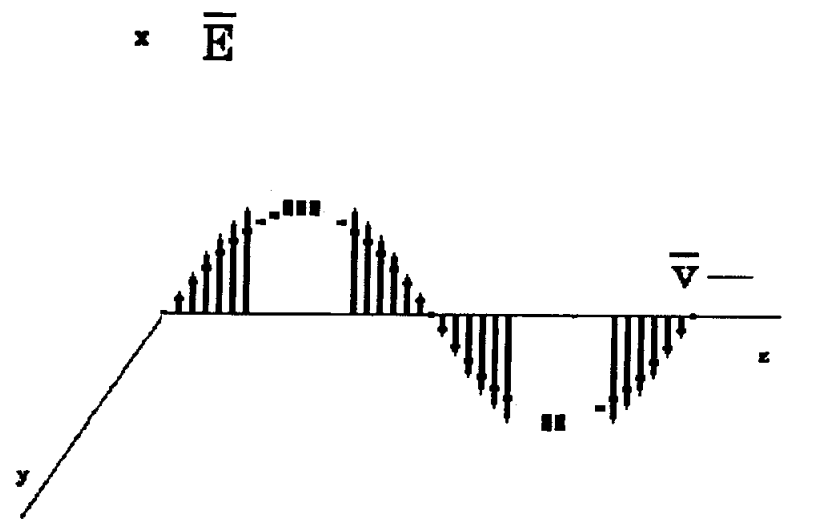
Figure 3:
Block diagram for asbestos analysis.

4. Auxiliary Information

Because of the subjective nature of asbestos analysis, certain concepts and procedures need to be discussed in more depth. This information will help the analyst understand why some of the procedures are carried out the way they are.

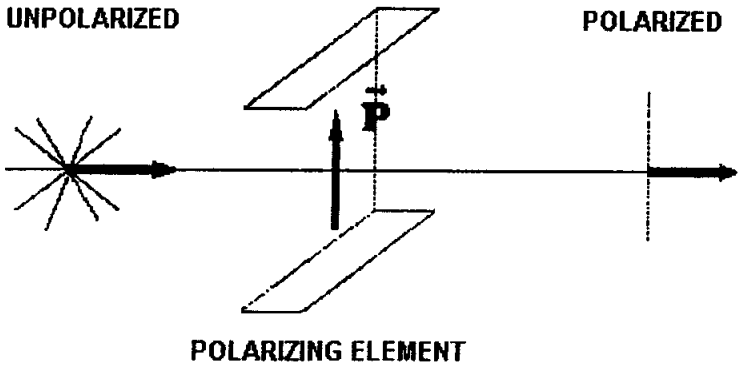
4.1. Light

Light is electromagnetic energy. It travels from its source in packets called quanta. It is instructive to consider light as a plane wave. The light has a direction of travel. Perpendicular to this and mutually perpendicular to each other, are two vector components. One is the magnetic vector and the other is the electric vector. We shall only be concerned with the electric vector (See Figure 4). In this description, the interaction of the electric vector and the mineral will describe all the observable phenomena. From a light source such as a microscope illuminator, light travels in all different directions from the filament. In any given direction away from the filament, the electric vector is perpendicular to the direction of travel of a light ray. While perpendicular, its orientation is random about the travel axis. If the electric vectors from all the light rays were lined up by passing the light through a filter that would only let light rays with electric vectors oriented in one direction pass, the light would then be **POLARIZED** (See Figure 5).



Plane wave with direction along z and electric vector along x

Figure 4:
A plane wave of light has its electric vector pointing always along the same axis. Here it is shown along the x axis as the light travels along the z axis.



A polarizing element allows only light vibrating in its polarization direction to pass through

Figure 5:
Light is polarized as it passes through a polarizing element.

Polarized light interacts with matter in the direction of the electric vector. This is the polarization direction. Using this property it is possible to use polarized light to probe different materials and identify them by how they interact with light.

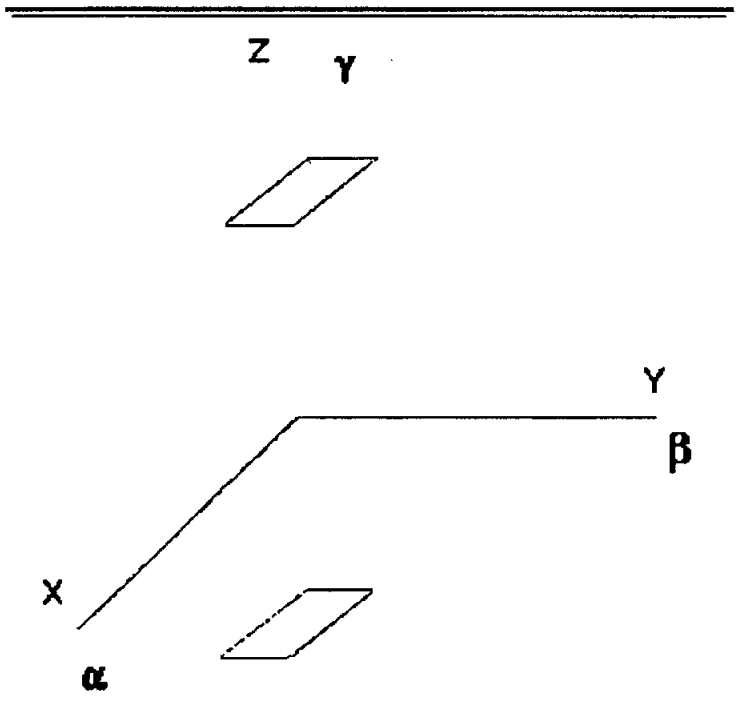
The speed of light in a vacuum is a constant at about 2.99 x 10^8 m/s. When light travels in different materials such as air, water, minerals or oil, it does not travel at this speed. It travels slower. This slowing is a function of both the material through which the light is traveling and the wavelength or frequency of the light. In general, the more dense the material, the slower the light travels. Also, generally, the higher the frequency, the slower the light will travel. The ratio of the speed of light in a vacuum to that in a material is called the index of refraction (n). It is usually measured at 589 nm (the sodium D line). If white light (light containing all the visible wavelengths) travels through a material, rays of longer wavelengths will travel faster than those of shorter wavelengths, this separation is called dispersion. Dispersion is used as an identifier of materials as described in Section 4.6.

4.2. Material Properties

Materials are either amorphous or crystalline. The difference between these two descriptions depends on the positions of the atoms in them. The atoms in amorphous materials are randomly arranged with no long range order. An example of an amorphous material is glass. The atoms in crystalline materials, on the other hand, are in regular arrays and have long range order. Most of the atoms can be found in highly predictable locations. Examples of crystalline material are salt, gold, and the asbestos minerals.

It is beyond the scope of this method to describe the different types of crystalline materials that can be found, or the full description of the classes into which they can fall. However, some general crystallography is provided below to give a foundation to the procedures described.

With the exception of anthophyllite, all the asbestos minerals belong to the monoclinic crystal type. The unit cell is the basic repeating unit of the crystal and for monoclinic crystals can be described as having three unequal sides, two 90° angles and one angle not equal to 90°. The orthorhombic group, of which anthophyllite is a member has three unequal sides and three 90° angles (see Figure 6). The unequal sides are a consequence of the complexity of fitting the different atoms into the unit cell. Although the atoms are in a regular array, that array is not symmetrical in all directions. There is long range order in the three major directions of the crystal. However, the order is different in each of the three directions. This has the effect that the index of refraction is different in each of the three directions. Using polarized light, we can investigate the index of refraction in each of the directions and identify the mineral or material under investigation. The indices α, β, and γ are used to identify the lowest, middle, and highest index of refraction respectively. The x direction, associated with α is called the fast axis. Conversely, the z direction is associated with γ and is the slow direction. Crocidolite has a along the fiber length making it "length-fast". The remainder of the asbestos minerals have the γ axis along the fiber length. They are called "length-slow". This orientation to fiber length is used to aid in the identification of asbestos.



Principal optical axes of a crystal

Figure 6:
The fast axis is shown along x and the slow axis along z.
For a length fast crystal this would be reversed.

4.3. Polarized Light Technique

Polarized light microscopy as described in this section uses the phase-polar microscope described in Section 3.2. A phase contrast microscope is fitted with two polarizing elements, one below and one above the sample. The polarizers have their polarization directions at right angles to each other. Depending on the tests performed, there may be a compensator between these two polarizing elements. Light emerging from a polarizing element has its electric vector pointing in the polarization direction of the element. The light will not be subsequently transmitted through a second element set at a right angle to the first element. Unless the light is altered as it passes from one element to the other, there is no transmission of light.

4.4. Angle of Extinction

Crystals which have different crystal regularity in two or three main directions are said to be anisotropic. They have a different index of refraction in each of the main directions. When such a crystal is inserted between the crossed polars, the field of view is no longer dark but shows the crystal in color. The color depends on the properties of the crystal. The light acts as if it travels through the crystal along the optical axes. If a crystal optical axis were lined up along one of the polarizing directions (either the polarizer or the analyzer) the light would appear to travel only in that direction, and it would blink out or go dark. The difference in degrees between the fiber direction and the angle at which it blinks out is called the angle of extinction. When this angle can be measured, it is useful in identifying the mineral (5.17.).

The procedure for measuring the angle of extinction is to first identify the polarization direction in the microscope. A commercial alignment slide can be used to establish the polarization directions or use anthophyllite or another suitable mineral. This mineral has a zero degree angle of extinction and will go dark to extinction as it aligns with the polarization directions. When a fiber of anthophyllite has gone to extinction, align the eyepiece reticle or graticule with the fiber so that there is a visual cue as to the direction of polarization in the field of view. Tape or otherwise secure the eyepiece in this position so it will not shift.

After the polarization direction has been identified in the field of view, move the particle of interest to the center of the field of view and align it with the polarization direction. For fibers, align the fiber along this direction. Note the angular reading of the rotating stage. Looking at the particle, rotate the stage until the fiber goes dark or "blinks out". Again note the reading of the stage. The difference in the first reading and the second is an angle of extinction.

The angle measured may vary as the orientation of the fiber changes about its long axis. Tables of mineralogical data usually report the maximum angle of extinction (5.14.). Asbestos forming minerals, when they exhibit an angle of extinction, usually do show an angle of extinction close to the reported maximum, or as appropriate depending on the substitution chemistry.

4.5. Crossed Polars with Compensator

When the optical axes of a crystal are not lined up along one of the polarizing directions (either the polarizer or the analyzer) part of the light travels along one axis and part travels along the other visible axis. This is characteristic of birefringent materials.

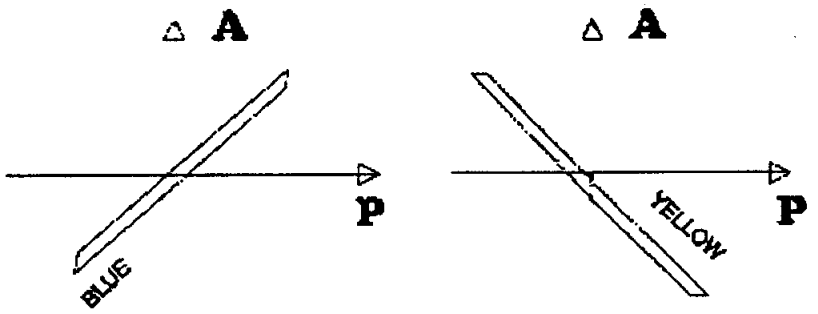
The color depends on the difference of the two visible indices of refraction and the thickness of the crystal. The maximum difference available is the difference between the α and the γ axes. This maximum difference is usually tabulated as the birefringence of the crystal.

For this test, align the fiber at 45° to the polarization directions in order to maximize the contribution to each of the optical axes. The colors seen are called retardation colors. They arise from the recombination of light which has traveled through the two separate directions of the crystal. One of the rays is retarded behind the other since the light in that direction travels slower. On recombination, some of the colors which make up white light are enhanced by constructive interference and some are suppressed by destructive interference. The result is a color dependent on the difference between the indices and the thickness of the crystal. The proper colors, thicknesses, and retardations are shown on a Michel-Levy chart (5.15.). The three items, retardation, thickness and birefringence are related by the following relationship:

$$R = t(n_\gamma - n_\alpha)$$

R = retardation, t = crystal thickness in μm, and $n_{\alpha,\gamma}$ = indices of refraction.

Examination of the equation for asbestos minerals reveals that the visible colors for almost all common asbestos minerals and fiber sizes are shades of gray and black. The eye is relatively poor at discriminating different shades of gray. It is very good at discriminating different colors. In order to compensate for the low retardation, a compensator is added to the light train between the polarization elements. The compensator used for this test is a gypsum plate of known thickness and birefringence. Such a compensator when oriented at 45° to the polarizer direction, provides a retardation of 530 nm of the 530 nm wavelength color. This enhances the red color and gives the background a characteristic red to red-magenta color. If this "full-wave" compensator is in place when the asbestos preparation is inserted into the light train, the colors seen on the fibers are quite different. Gypsum, like asbestos has a fast axis and a slow axis. When a fiber is aligned with its fast axis in the same direction as the fast axis of the gypsum plate, the ray vibrating in the slow direction is retarded by both the asbestos and the gypsum. This results in a higher retardation than would be present for either of the two minerals. The color seen is a second order blue. When the fiber is rotated 90° using the rotating stage, as shown in Figure 7, the slow direction of the fiber is now aligned with the fast direction of the gysum and the fast direction of the fiber is aligned with the slow direction of the gypsum. Thus, one ray vibrates faster in the fast direction of the gypsum, and slower in the slow direction of the fiber; the other ray will vibrate slower in the slow direction of the gypsum and faster in the fast direction of the fiber. In this case, the effect is subtractive and the color seen is a first order yellow. As long as the fiber thickness does not add appreciably to the color, the same basic colors will be seen for all asbestos types except crocidolite. In crocidolite the colors will be weaker, may be in the opposite directions, and will be altered by the blue absorption color natural to crocidolite. Hundreds of other materials will give the same colors as asbestos, and therefore, this test is not definitive for asbestos.



Birefringent fibers will change color as the microscope stage is rotated.
Asbestos fibers except crocidolite will show colors as shown here
under the conditions of crossed polars and a 1st order red compensator.

Figure 7:
The birefringence test showing that in one orientation,
the fiber is blue while in the other orientation it is yellow.

The test is useful in discriminating against fiberglass or other amorphous fibers such as some synthetic fibers. Certain synthetic fibers will show retardation colors different than asbestos; however, there are some forms of polyethylene and aramid which will show morphology and retardation colors similar to asbestos minerals. This test must be supplemented with a positive identification test when birefringent fibers are present which can not be excluded by morphology. This test is relatively ineffective for use on fibers less than 1 μm in diameter. For positive confirmation TEM or SEM should be used if no larger bundles or fibers are visible.

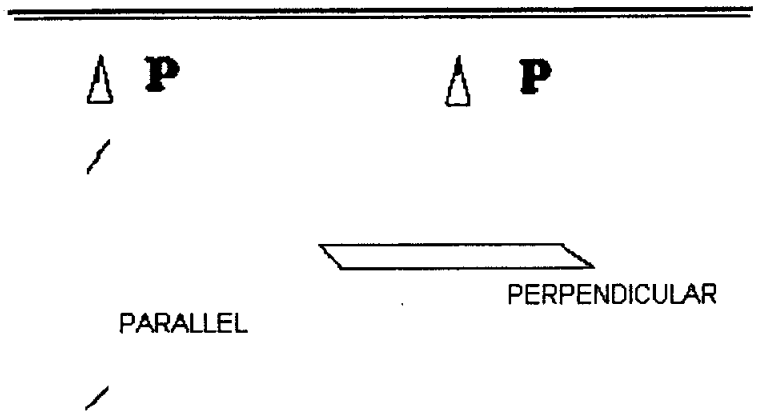
4.6. Dispersion Staining

Dispersion microscopy or dispersion staining is the method of choice for the identification of asbestos in bulk materials. Becke line analysis is used by some laboratories and yields the same results as does dispersion staining for asbestos and can be used in lieu of dispersion staining. Dispersion staining is performed on the same platform as the phase-polar analysis with the analyzer and compensator removed. One polarizing element remains to define the direction of the light so that the different indices of refraction of the fibers may be separately determined. Dispersion microscopy is a dark-field technique when used for asbestos. Particles are imaged with scattered light. Light which is unscattered is blocked from reaching the eye either by the back field image mask in a McCrone objective or a back field image mask in the phase condenser. The most convenient method is to use the rotating phase condenser to move an oversized phase ring into place. The ideal size for this ring is for the central disk to be just larger than the objective entry aperture as viewed in the back focal plane. The larger the disk, the less scattered light reaches the eye. This will have the effect of diminishing the intensity of dispersion color and will shift the actual color seen. The colors seen vary even on microscopes from the same manufacturer. This is due to the different bands of wavelength exclusion by different mask sizes. The mask may either reside in the condenser or in the objective back focal plane. It is imperative that the analyst determine by experimentation with asbestos standards what the appropriate

colors should be for each asbestos type. The colors depend also on the temperature of the preparation and the exact chemistry of the asbestos. Therefore, some slight differences from the standards should be allowed. This is not a serious problem for commercial asbestos uses.

This technique is used for identification of the indices of refraction for fibers by recognition of color. There is no direct numerical readout of the index of refraction. Correlation of color to actual index of refraction is possible by referral to published conversion tables. (5.20.) This is not necessary for the analysis of asbestos. Recognition of appropriate colors along with the proper morphology are deemed sufficient to identify the commercial asbestos minerals. Other techniques including SEM, TEM, and XRD may be required to provide additional information in order to identify other types of asbestos.

Make a preparation in the suspected matching high dispersion oil, e.g., n = 1.550 for chrysotile. Perform the preliminary tests to determine whether the fibers are birefringent or not. Take note of the morphological character. Wavy fibers are indicative of chrysotile while long, straight, thin, frayed fibers are indicative of amphibole asbestos. This can aid in the selection of the appropriate matching oil. The microscope is set up and the polarization direction is noted as in Section 4.4. Align a fiber with the polarization direction as shown in Figure 8. Note the color. This is the color parallel to the polarizer. Then rotate the fiber by rotating the stage 90° so that the polarization direction is across the fiber. This is the perpendicular position. Again note the color (See Figure 8). **Both** colors must be consistent with standard asbestos minerals in the correct direction for a positive identification of asbestos. If only one of the colors is correct while the other is not, the identification is not positive. If the colors in both directions are bluish-white, the analyst has chosen a matching index oil which is higher than the correct matching oil, e.g. the analyst has used n = 1.620 where chrysotile is present. The next lower oil (Section 3.5.) should be used to prepare another specimen. If the color in both directions is yellow-white to straw-yellow-white, this indicates that the index of the oil is lower than the index of the fiber, e.g. the preparation is in n = 1.550 while anthophyllite is present. Select the next higher oil (Section 3.5.) and prepare another slide. Continue in this fashion until a positive identification of all asbestos species present has been made or all possible asbestos species have been ruled out by negative results in this test.



Fibers are shown parallel and perpendicular to the polarizer.

Figure 8:
For the dispersion staining test,
the fibers are lined up first with the polarizer direction and then against it.

Certain plant fibers can have similar dispersion colors as asbestos. Take care to note and evaluate the morphology of the fibers or remove the plant fibers in pre-preparation. Coating material on the fibers such as carbonate or vinyl may destroy the dispersion color. Usually, there will be some outcropping of fiber which will show the colors sufficient for identification. When this is not the case, treat the sample as described in Section 3.3. and then perform dispersion staining. Some samples will yield to Becke line analysis if they are coated or electron microscopy can be used for identification.

5. REFERENCES

5.1. **Crane, D.T.,** *Asbestos in Air,* OSHA method ID160, Revised November **1992.**

5.2. **Ford, W.E.,** *Dana's Textbook of Mineralogy; Fourth Ed.;* John Wiley and Son, New York, **1950,** p. vii.

5.3. **Selikoff,.I.J., Lee, D.H.K.,** *Asbestos and Disease,* Academic Press, New York, **1978,** pp. 3,20.

5.4. *Women Inspectors of Factories. Annual Report for 1898,* H.M. Statistical Office, London, p. 170(**1898**).

5.5. **Selikoff,.I.J., Lee, D.H.K.,** *Asbestos and Disease,* Academic Press, New York, **1978**, pp. 26,30.

5.6. **Campbell, W.J.,** et al, *Selected Silicate Minerals and Their Asbestiform Varieties,* United States Department of the Interior, Bureau of Mines, Information Circular 8751, **1977**.

5.7. *Asbestos,* Code of Federal Regulations, 29 CFR 1910.1001 and 29 CFR 1926.58.

5.8. *National Emission Standards for Hazardous Air Pollutants; Asbestos NESHAP Revision,* Federal Register, Vol. 55, No. 224, **20 November 1990**, p. 48410.

5.9. **Ross, M.** *The Asbestos Minerals: Definitions, Description, Modes of Formation, Physical and Chemical Properties and Health Risk to the Mining Community,* Nation Bureau of Standards Special Publication, Washington, D.C., **1977**.

5.10. Lilis, R., Fibrous Zeolites and Endemic Mesothelioma in Cappadocia, Turkey, *J. Occ Medicine,* **1981**, 23, (8),548-550.

5.11. *Occupational Exposure to Asbestos - 1972,* U.S. Department of Health Education and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, HSM-72-10267.

5.12. **Campbell,W.J.,** et al, Relationship of Mineral Habit to Size *Characteristics for Tremolite Fragments and Fibers,* United States Department of the Interior, Bureau of Mines, Information Circular 8367, **1979**.

5.13. **Mefford, D.,** DCM Laboratory, Denver, private communication, **July 1987**.

5.14. **Deer, W.A., Howie, R.A., Zussman, J.,** *Rock Forming Minerals,* Longman, Thetford, UK, **1974**.

5.15. **Kerr,P.F.,** *Optical Mineralogy; Third Ed.* McGraw-Hill, New York, **1959**.

5.16. **Veblen, D.R. (Ed.),** *Amphiboles and Other Hydrous Pyriboles - Mineralogy,* Reviews in Mineralogy, Vol 9A, Michigan, **1982**, pp 1 - 102.

5.17. **Dixon, W.C.,** *Applications of Optical Microscopy in the Analysis of Asbestos and Quartz,* ACS Symposium Series, No. 120, Analytical Techniques in Occupational Health Chemistry, **1979**.

5.18. Polarized Light Microscopy, McCrone Research Institute, Chicago, **1976**.

5.19. Asbestos Identification, McCrone Research Institute, G & G printers, Chicago, **1987**.

5.20. **McCrone, W.C.,** Calculation of Refractive Indices from Dispersion Staining Data, The Microscope, No 37, Chicago, **1989**.

5.21. **Levadie, B. (Ed.),** *Asbestos and Other Health Related Silicates,ASTM Technical Publication 834,* ASTM, Philadelphia 1982.

5.22. **Steel, E. and Wylie, A., Riordan, P.H. (Ed.),** Mineralogical Characteristics of Asbestos, *Geology of Asbestos Deposits,* pp. 93-101, SME-AIME, 1981.

5.23. **Zussman, J.,** The Mineralogy of Asbestos, *Asbestos: Properties, Applications and Hazards,* pp. 45-67 Wiley, 1979.

ATTACHMENT 8

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16 May 1989

Kelly F. Bailey
Vulcan Materials Company
P.O.Box 7497
Birmingham, Alabama 35253-0497

Dear Kelly,

I received your letter of April 10 requesting information regarding analysis of non-asbestiform fibers especially as refers to actinolite. As you indicated, the general procedure for actinolite, tremolite and anthophyllite is the same.

As you know, OSHA standards require that fiber counts be based on phase contrast light microscopy (PCM). When appropriately used, PCM can be a very powerful tool in analysis. OSHA allows the use of "differential counting" which is the exclusion from PCM counts of certain fibers meeting the size and shape criteria for fibers (longer than or equal to 5 um, and aspect ratio greater than or equal to 3:1). This exclusion is normally used for obvious contaminants such as fiberglass, gypsum, natural and synthetic organic fibers and the like. In practice, all available information is evaluated by an analyst while making his decisions.

The information assessed by the analyst may include the operation involved in the sampling, the industry type, any known interferences, polarized light microscopy (PLM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM) as well as any other information supplied by the sampler or company. But, most important is the analyst's personal experience as a microscopist. This provides a mental catalog of appropriate fiber morphologies and responses to PLM, SEM, TEM etc. An analyst is trained by exposure to known fiber types and different analytical problems. In this way, much of the limitation of PCM can be overcome.

Morphological identification is the technique generally applied to the problem of determining the difference between asbestiform fibers and other OSHA fibers such as cleavage fragments. When crushed, ground or otherwise processed, fibers from asbestos ore show curvature indicating high tensile strength. They show frayed or tinely divided ends, they show branching and very high aspect ratios. They may show striations internally. Cleavage fragments, on the other hand tend to be prismatic, lathlike or acicular in morphology. They do not show curvature and do not show branching or frayed ends. The internal structure tends to be uniform. The ends of the fibers look stepped rather than the asbestos "broom" ends.

As the fiber diameter decreases, our ability to distinguish these features decreases as well. For thin fibers, the identification may be made by

association. If a sample contains true asbestos fibers, there will be longer, identifiable fibers elsewhere on the filter or in the bulk sample of material that we request with each set of samples submitted to our laboratory. If these appear, or if they show patent non-asbestos morphology this information will aid in our analysis.

For the larger fibers, we generally do not have much trouble. However, as the size of the fiber decreases, the analysis is more likely to include all fibers unless they are specifically ruled out by prior SEM or TEM analysis which would look for the same sorts of morphological evidence as well as a definite identification of the minerals by chemistry and crystal structure.

As you can see, we apply and encourage to be applied a broad range of technique to the problem of fiber analysis under the OSHA standards. Should you have any further questions, do not hesitate to contact us.

Sincerely,

Daniel T. Crane
Supervisory Physical Scientist