American Thoracic Society
MEDICAL SECTION OF THE AMERICAN LUNG ASSOCIATION

HEALTH EFFECTS OF TREMOLITE[1]

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The risks of exposure to the major commercial asbestos fiber types encountered in mining, milling, manufacturing, and product use are well known. There is increasing consensus that amphibole exposure (crocidolite and amosite) is more hazardous than exposure to chrysotile, particularly as it relates to mesothelioma risk. In addition, there has been uncertainty in regard to whether the chrysotile risk is attributable to this fiber or to its com-

In addition to chrysotile ore, tremolite con-

Some epidemiologic studies of these industries have reported excess lung cancers and mesotheliomas, an appropriate cause for concern. Assessment of tremolite exposure risk has also been approached by animal studies and mineralogic analysis of human lungs.

A troublesome issue has been the mineralogic distinction between fibers and cleavage

biologic implications.

Federal regulatory agencies have participated in the intense debate on tremolite issues. 'Bemolite-contaminated play sand has been

the Consumer Product Safety Commission. The Occupational Safety and Health Administration (OSHA) has had a long interest in how (and whether) nonasbestiform amphiboles (including tremolite) should be regulated. The agency recently proposed revised standards for occupational exposure to asbestos that would omit nonasbestiform amphiboles

The Scientific Assembly on Environmental and Occupational Health of the American Thoracic Society (ATS) appointed a Com-

Tremolite in 1988.

Its charge was to critically assess the scientif-

tremolite exposures. This report will address the epidemiologic, animal, and mineralogic information, and comment on some of the regulatory issues. A draft report of the committee was presented to the membership at the annual meeting of the ATS in May 1989, in a public forum. Extensive discussion at that time and a substantial number of written comments and other materials were given to the committee by a wide variety of interested persons and organizations in the months after the annual meeting. The committee appreciates these responses, has carefully considered all of the submissions, and has made considerable revisions of the draft report.

Mineralogic Issues

As noted above, the focus on tremolite has raised the issue of the importance of cleavage fragments as opposed to asbestiform fibers. The fundamental issue is whether two fibrous particles of identical size and shape will have different biologic properties if the particles are pieces of mineral that have broken off a larger sample parallel to a crystal face (i.e., cleavage fragments) as opposed to particles that have originally grown in a fibrous habit (i.e., asbestiform fibers).

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 fragments and asbestiform fibers, although theoretically clear, is in practice extremely murky. Some mineralogists believe that these two types of particles are always distinct, whereas others believe that they shade off one into the other and that intermediate forms (byssolite) exist. Further, these same submissions were at odds with each other in identifying particular samples used in various experiments as asbestiform fibers or cleavage fragments. To complicate matters, it was also suggested to us that the important distinction is not that between cleavage fragments nonas-bestiform fibers but between bestiform and asbestiform fibers.

Because of the lack of consensus among mineralogists, as well as the limited information about the minerals present in most published human and animal data (i.e., whether the particles used or observed really are fibers or cleavage fragments), we have to a great extent ignored the distinction and ended up treating most of the data as based on "fibers" of various sizes. The committee recognizes that this is not an ideal solution, and where stronger evidence of the cleavage fragment or asbestiform nature of a particular fiber ex-

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is reasonable mineralogic unanimity both on general definition and the classification of specific samples, and then animal experimentation with such classified materials, it appears to us impossible to draw general conclusions about biologic effects based on the distinction between cleavage fragments and asbestiform fibers.

Epidemiologic Evidence

Epidemiologic information concerning tremolite as a potential health risk comes from studies of workers occupationally exposed as a consequence of tremolitic contamination of ores (chrysotile, vermiculite, and talc) and of residents of certain regions in Turkey where exposures result from naturally occurring deposits.

Chrysotile

There is strong epidemiologic evidence that the amphiboles amosite and crocidolite are considerably more dangerous than chrysotile in causing mesothelioma (1). Because of this and because most chrysotile deposits also contain the amphibole tremolite, it is possible that the relatively few mesothelioma cases among chrysotile workers may actually have been caused by tremolite asbestos. Supporting evidence of the role of tremolite comes primarily from mineralogic analyses of lungs, which have found that the most important difference between mesothelioma cases and matched control subjects is the amphibole content, including tremolite (2, 3).

It should be understood that mineralogic analyses of the lungs have been used as an indicator of exposure because the tremolite usually constitutes only a very small and variable fraction of the chrysotile ore, and therefore, measurements of tremolite exposure levels for these chrysotile workers do not exist.

Vermiculite

Workers from two vermiculite mines have been studied: one in Libby, Montana, studied by two independent groups of researchers (4-7), and one in South Carolina (8). Ores from both mines are reported to have been contaminated with tremolite asbestos (and nonasbestiform tremolite), but fiber exposure levels were lower in the South Carolina mine.

[1] Reprints may be obtained from your state or local Lung Association.

However, some uncertainty regarding tremolite asbestos contamination at the Libby mine has been expressed (Tibor Zoltai, personal communication to the committee, citing R. L. Bates, Geology *of the Industrial Rocks and Minerals*, Harper and Brothers, 1960). By contrast, a member of this committee (P. Sebastien) was involved in the mineralogic evaluation of the Libby mine and is convinced that the deposits contain "true asbestiform fibers."

The Libby cohort included workers employed for at least one year. Exposure estimates (in fibers per milliliter) were based on measurements in the 1970s using the membrane filter method and on trends in measurements made in the past using the midget impinger method. In this cohort, with a mean length of employment of 8.7 yr, there were excess pneumoconioses (eight cases), four cases of mesothelioma, and an excess lung cancer risk (20 yr or more from hire: 15 observed, 5.3 expected, for a standardized mortality ratio [SMR] of 2.85) (4). Though there was considerable variability in the SMR, the lung cancer risk was related significantly to estimated cumulative exposure.

Because of the nonfibrous nature of vermiculite and the finding of pneumoconioses and elevated lung cancer, tremolite was interpreted to be the causative agent. Additionally, the morbidity studies (5, 7) found evidence of fibrotic effects, including parenchymal small opacities, pleural thickening, and pleural calcification.

Taken together, the findings for this cohort indicate that tremolite asbestos exposures result in respiratory health consequences similar to other forms of asbestos exposure, including lung cancer and mesothelioma.

Among the smaller cohort (194 subjects) of South Carolina vermiculite miners employed for at least six months, there were four lung cancer deaths versus 3.3 expected, and no mesothelioma or pneumoconiosis cases (8). Using the dose-response relationship for Montana, the investigators calculated that a detectable increase in lung cancer risk would not have been expected because of the low exposure levels and the small size of the cohort. The results therefore do not add information: they are consistent with both the Libby results *and* a conclusion of no attributable health risk.

The observation for the Libby cohort of a dose-response relationship for lung cancer risk is important evidence of tremolite asbestos as a carcinogen in vermiculite mining. However, because this is based on only one cohort, and no data on other relatively large populations of vermiculite miners are available, the appropriate caution in interpreting nonreplicated epidemiologic study results is warranted, an approach also suggested by the indicated reservations regarding the mineralogy of the Libby deposit.

Talc

Two cohorts of New York State talc miners have been studied for evidence of health risks.

One group, 260 workers employed at least 15 yr in several New York mines with asbestiform tremolite contamination (9, 10), was the subject of a proportional mortality study. Of all 108 deaths, 27% were due to pneumoconiosis, and there was one peritoneal mesothelioma; however, because talc can cause lung fibrosis and information concerning other exposures of workers was not available, these deaths cannot be attributed to tremolite exposure. An excess in lung cancer risk was noted: the 13 lung cancer cases constituted 12% of all deaths compared with an expected 3.7% based on 1955 U.S. rates. Risk did not exhibit a relationship with duration of employment. A firm conclusion of an elevated lung cancer risk cannot be made from this study for a number of reasons, including the lack of a dose-response relationship, the potential problems of all proportional mortality studies, the fact that New York lung cancer rates during 1950-1959 were higher than U.S. rates (by 29%), and the lack of smoking information.

Employees of a New York talc mine were the subjects of three published papers and an unpublished report by the National Institute for Occupational Safety and Health (NIOSH) (J. Gamble, G. Piacitclli, unpublished information). Brown and colleagues (11) reported that ore samples were found to contain asbestiform minerals, including tremolite, and to be similar to that from other New York mines. There has, however, been a dispute regarding the mineralogic composition of these talc deposits (A. G. Wylie, personal communication to the committee).

The first of the studies (11) included 398 men hired during 1947-1959; the second (12), 655 men hired during 1948-1977; the third was primarily a reanalysis of the Stille and Tabershaw data (13). All three had important limitations in their data analyses: the first study considered follow-up time since hire but not any indicator of exposure, though job records were available; the second separately analyzed workers with and without previous employment elsewhere but did not consider follow-up period or exposure indicators; the third considered duration of employment and previous employment elsewhere but did not control for follow-up time.

NIOSH investigators recently expanded the cohort to men hired during 1947-1978, continued follow-up of the cohort through 1983, considered both follow-up period and length of employment, and included a nested case-control study of all confirmed lung cancer cases (J. Gamble, G. Piacitelli, unpublished observation). The results of this latest report will be reviewed here because it contains the most recent data and complete analyses.

Twenty years or more after hire (which includes 13 of the 17 lung cancer cases occurring through 1983), the only significantly elevated lung cancer risk was observed among workers employed less than one year (eight observed, 2.24 expected, SMR = 357.2; one-tailed $p < 0.01$). By contrast, among those employed at least one year, the risk was not significantly elevated (five observed, 2.81 expected; one-tailed $p > 0.15$), and there was not a trend of risk with duration employed (for durations of 1 to 9, 10 to 19, and ≥ 20 yr, the SMR were 82 (one observed, 1.2 expected); 446 (two observed, 0.5 expected); and 176 (two observed, 1.1 expected), respectively.

This finding of an elevated risk restricted primarily to short-term workers is consistent with several epidemiologic studies of other exposures; it has been noted that short-term workers are particularly difficult to evaluate and may differ from other workers in ways related to cancer risk, possibly including personal lifestyles (14).

The nested case-control study of all 22 lung cancer cases (including five that occurred after 1983), each matched with three control subjects, was able to evaluate the potential role of smoking and other occupational exposures. Smoking was found to be a significant factor, but there was no evidence of an effect of other occupational exposure or length of employment at the mine; in fact, there was a generally decreasing risk with duration of mine employment.

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.

NIOSH also conducted a study of 392 miners who had worked for at least one year in Vermont talc mines, in which the ore was reported to be free of asbestos contamination (15). Miners were found to have had excess lung cancer risk (five observed, 1.15 expected, SMR = 4.35; $p < 0.01$), though millers did not (two observed, 1.96 expected, SMR = 1.02), even though millers were believed to have had higher exposure levels. Risk was not evaluated in relation to any other indicator of exposure. The investigators mentioned several potential influencing factors for which no information was available, including radon exposure, smoking, and previous work in a local talc mine with tremolite contamination. These results do not demonstrate an exposure-related lung cancer risk.

A study of a large cohort (2,000 subjects) of Italian talc miners (16) employed at least one year found no evidence of excess cancer risk. The ore is reputed to be one of the purest anywhere, although analyses of the ore found a small amount of tremolite. An observed pneumoconiosis risk was attributed by the investigators to silica exposure.

A National Cancer Institute (NCI) study of workers in three ceramic manufacturing plants (17) categorized workers with high silica dust exposure into three categories of talc exposure: none, fibrous (tremolitic) talc, and nonfibrous talc, stated to contain no asbestos. There was not a significantly elevated lung cancer risk among either the nontalc workers (18 observed, 13.2 expected, SMR = 1.37) or the fibrous talc workers (five observed, 2.9 expected, SMR = 1.74), but the nonfibrous talc group had a significantly elevated lung cancer risk (21 observed, 8.3 expected, SMR = 2.54; p < 0.001) that exhibited a trend with duration of employment in nonfibrous talc jobs. There are a number of methodologic problems with this study, including the lack of smoking information, the relatively small number of fibrous talc workers, and the use of U.S. rates rather than local mortality rates. However, as reported, these results do not support a carcinogenic role of tremolite because the tremolitic talc appeared to be less hazardous than the asbestos-free talc.

In summary, none of the talc studies has convincingly demonstrated an increased lung cancer risk reliably attributed to exposure, and the very similar results for New York and Vermont mine workers, whose tremolite exposures were apparently different, do not support a role for tremolite as a lung carcinogen in talc mining (whether the tremolite was asbestiform or not).

Environmental Exposures in Turkey

Elevated mesothelioma risk has been observed among inhabitants of rural areas in Turkey with naturally occurring asbestiform tremolite (18). Although there is no occupational asbestos exposure in the area, some residents have apparently had very high tremolite exposures as a consequence of numerous natural outcrops and the use of the mineral dust in whitewash and stucco for houses. Patients with pleural plaques, diffuse thickening, and diffuse pulmonary fibrosis have also been reported. The lack of evidence of any other fiber exposure strongly suggests tremolite asbestos as the cause.

Finally-although not tremolite – short, nonasbestiform amphibole exposures (cummingtonite-grunerite) have occurred in two populations that have been studied for mortality experience. Both the Homestake and Reserve Mining studies failed to show either an overall excess lung cancer risk or a gradient of such risk with increasing estimated past exposures within the cohorts (19, 20).

Summary of the Epidemiologic Evidence

In summarizing the limited epidemiologic data on tremolite exposure, the Montana vermiculite workers demonstrated a mesothelioma risk and an excess lung cancer risk, which is dose-related and further strengthens the conclusion that tremolite asbestos should be considered carcinogenic and should be regulated accordingly. The dose-response relationship based on the Montana experience can be used to establish allowable occupational and environmental exposure levels for asbestiform tremolite Additional support for a role of tremolite asbestos as a human carcinogen comes from the lung burden analyses of Quebec chrysotile miners (see following section). However, it has not been demonstrated convincingly that talc workers have an exposure-related cancer risk, and there is continuing controversy as to whether the relevant talc deposits contained asbestiform tremolite.

Lung Burden Studies of Tremolite

Relatively little information is available on the tremolite content of human lung in occupationally or environmentally exposed populations, or on the fibers to which various populations have been exposed, but the data that do exist indicate that both fiber concentration and fiber size can be correlated with disease patterns.

It should be noted that mineral analysis of fiber content in the lungs of these workers does present some problems. For one thing, chrysotile tends to disappear rapidly from the lung, so that the typical lung of a chrysotile miner will contain more tremolite than chrysotile, even though tremolite constitutes only a few percent of the ore. Second, different research groups have chosen to count fibers of different minimal lengths in their analyses; there are valid reasons for each approach, but the results are not always comparable, as noted below.

In the lungs of Quebec and Cypriot chrysotile miners, tremolite is the predominant residual fiber, even though it constitutes only a few percent of the original ore (21, 22). Chrysotile-derived tremolite is also seen in substantial amounts in the lungs of South Carolinian textile workers, albeit in a lesser ratio to chrysotile (23-25). In the Quebec mining and milling population, the concentration of tremolite in workers with asbestosis is, overall, markedly increased compared to those with no parenchymal disease (26). In both the Quebec mining and milling population, and the South Carolinian textile workers, there is a good correlation between the concentration of tremolite per gram of lung tissue and the degree of interstitial fibrosis (asbestosis) (23, 27); there is also, however, a reasonably strong correlation between chrysotile concentration and severity of fibrosis (23, 27), and the present data do not indicate whether tremolite or chrysotile is more important in this process.

Compared with the incidence in workers heavily exposed to amosite or crocidolite, mesotheliomas are relatively scarce in the Quebec chrysotile mining population. Although analysis shows that occasional cases from the mining regions have amosite and crocidolite in their lungs (particularly workers from the region of the town of Asbestos [28]), most of the cases, and especially those from the region of Thetford mines, contain only tremolite and chrysotile (the former in larger amounts than the latter [B. W. Case, unpublished data; 29]), indicating that one or both of these fibers is the agent inducing mesothelioma. It is noteworthy that the median tremolite content of the lungs of the Quebec workers with mesothelioma is somewhat above that of those with asbestosis (2). This is in direct contrast to the situation in workers with heavy exposure to amosite or crocidolite, where mesothelioma appears at far lower lung burdens than does asbestosis (2).

If one counts all fibers, then the tremolite found in the lungs of Quebec chrysotile workers appears to be a relatively short, low-aspect ratio fiber (geometric mean length 2 μm; geometric mean aspect ratio, 8:1 to 10:1), particularly when compared with the amosite and crocidolite found in the lungs of shipyard workers or insulators (26). If one counts only fibers longer than 5 μm, as does the group at McGill, then in fact the geometric mean aspect ratio of tremolite fibers is measured at greater than 20:1 (B. W. Case, unpublished data).

Tremolite exposure from ambient air has been documented by lung analysis in various environmentally exposed populations. Tremolite, like other amphiboles, appears to accumulate readily in lungs at all exposure levels and is the most commonly encountered amphibole fiber in the lungs of urban dwellers in North America (21). Here, again, the fiber is a short, low-aspect ratio mineral (actually considerably shorter than the fibers seen in chrysotile miners), which is probably derived from chrysotile ore (21).

Of particular interest is the lung burden of the residents of the Quebec mining townships of Asbestos (28) and Thetford Mines/Black Lake (28, 30-32). Analysis of lung asbestos content in the latter shows that these lungs contain approximately as much tremolite as they do chrysotile (28, 30–32), even though the ambient chrysotile level is several hundred-fold higher than the ambient tremolite level (33). In residents of Asbestos, however, there is no tremolite excess, presumably because the ambient tremolite concentration (0.0002 fibers/ml) is much less than that in Thetford Mines (0.0015 fibers/ml) (33).

Studies from two different laboratories have confirmed that the population near Thetford Mines who have never been employed in the asbestos industry carry a higher tremolite, as well as chrysotile, burden compared with residents of North American urban areas (28, 30-32). The McGill group studies have also recently shown that this lung burden is significantly correlated both with distance of domicile from the mines and with time lived in the mining region (31, 32). Even greater burdens are found in those who have household contact exposure because a close relative works in the mining and milling industry (31).

Although this burden is apparently occasionally associated with pleural plaques (plaques were seen in seven of 72 cases studied by Case and coworkers [unpublished data; 28]), particularly in individuals such as farmers who encounter dust from soil (34), there is no epidemiologic evidence that either chrysotile or tremolite at this level produces an excess of lung cancer or mesothelioma.

By contrast, studies of the lung content of populations environmentally exposed to longer, and usually much higher, aspect ratio tremolite indicate that this type of fiber is a potent mesothelial carcinogen. Yazioglu and associates (35) reported on a population in Turkey, and Langer and coworkers (36) and Constantopoulos and colleagues (37) reported on a population in Greece, with substantial incidences of mesothelioma and exposure to long fibers with an aspect ratio greater than 50. It has also been suggested that long tremolite fibers are responsible for some of the mesotheliomas seen in persons other than chrysotile miners in North America (3, 38). The exact role of length versus aspect ratio is uncertain because several apparently environmentally induced mesotheliomas have been reported from an area of Corsica, where analysis of lung content indicates that the tremolite fibers are fairly long (probably on average as long as the amosite fibers seen in the lungs of shipyard and insulation workers in North America), but the aspect ratio is lower (considerably lower than is found for amosite or crocidolite) (39).

The evidence on mineral lung burden implies that long, high-aspect ratio, tremolite fibers behave much like other amphiboles of comparable size and are particularly dangerous because of their propensity to induce mesothelioma. 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. However, this statement is made with considerable caution because the populations with exposure to this type of mineral have also had extremely high chrysotile exposure, an exposure that, as noted above, is not well reflected in mineral analyses of lung content; the role of chrysotile versus tremolite in producing disease in these patients cannot be clearly sorted out.

Animal Studies

Only a small number of animal studies have used tremolite, and these studies are confounded by difficulties in definition of the exact mineral used (particularly its size, length, and shape) and, in some instances, by flawed experimental design or poor survival of animals.

Much of the interest in tremolite arose from the fact that it contaminates talc (40). Smith and colleagues (41-44) found that a commercial New York talc sample containing 50% very large diameter tremolite (1 μm mean diameter) produced no tumors when injected into the pleural cavity of hamsters. However, mesotheliomas were produced with what are described as long and thin or asbestiform fibers from other samples of tremolitic talc. Unfortunately, no details of the exact fiber sizes are provided, and it is impossible to determine whether these samples would be properly classified as asbestiform or not.

The most important and widely cited studies in regard to tremolite are those by Stanton and colleagues (45-48). Using a large number of different types of mineral fibers implanted directly into rat pleural cavities, they showed that fiber carcinogenesis was related to fiber size, shape, and durability, rather than to chemical composition per se. Although Stanton and colleagues found that fibers longer than 8 μm and narrower than 0.25 μm in diameter were, in general, the most carcinogenic, they did observe a very high incidence of tumors with tremolite, which in fact was much shorter and broader. Their data indicate that tremolite fiber populations in which the majority of the fibers are greater than 4 μm in length and have a diameter of less than 1.5 μm were among the most carcinogenic (100% tumor probability) of all the different types of minerals tested when using the intrapleural injection model.

Wagner and associates (49) tested three samples of tremolite. A sample prepared from a South Korean rock that was about 80% fibrous, with about one-third of the fibers longer than 8 μm and most less than 0.6 μm in diameter, produced mesotheliomas in 30% of the animals. By contrast, two other samples that had few fibers failed to produce any tumors. The same group also studied these fibers *in vitro*, and the Korean fiber showed the greatest cytotoxic effects as measured by LDH, beta-glucuronidase release, and giant cell formation.

Davis and coworkers (50) tested an asbestiform Korean tremolite in an inhalation experiment and found two mesotheliomas and 16 carcinomas in 40 animals. No tumors were seen in the control animals. Inspection of their data indicates that approximately 60% of the fibers were shorter than 4 μm and thicker than 0.25 μm, and 90% had diameters of less than 1 μm. The investigators noted that the tremolite was one of the most carcinogenic materials they had used.

Davis and coworkers are continuing experiments with tremolite (communication to the committee). Preliminary analysis of their data indicates that asbestiform varieties of tremolite are highly carcinogenic and produce over 90% incidence of mesothelioma within 18 months; it should be noted that the mean aspect ratio of these fibers was approximately 8:1. Of particular interest is the fact that two samples which Davis describes as containing elongated spicules rather than true asbestiform fibers (and described by A. G. Wylie in a submission to this committee as byssolite) produced tumors in 69 and 12% of the animals. As well, a sample of tremolite containing many particles with an aspect ratio greater than 3:1, but described by Davis and coworkers as "prismatic" rather than asbestiform, produced mesotheliomas in 6% of the animals. Davis and colleagues make the point that it is difficult to determine whether size and shape are the most important determinants of carcinogenicity in these experiments because the numbers of fibers injected vary greatly among the different samples, and there is a close correlation between fiber shape and fiber number in these preparations. Thus, the most carcinogenic samples had both the highest total number of fibers and the greatest number longer than 5, 10, or 20 pm in length.

It should be noted that many of the original studies of chrysotile toxicity by inhalation may have been influenced by the presence of tremolite. Wagner and associates (51) noted that although no tremolite was found in the original chrysotile fiber samples and fibers taken from the dusting chambers using UICC chrysotile A and a fine Quebec chrysotile, the presence of the fiber was indicated clearly on reanalysis of the lung burdens of exposed rats. Langer and Nolan (52) were also unable to find tremolite in any specimen of Quebec chrysotile, even though studies of the lungs of both miners and those living in the neighborhood of miners clearly indicate the presence of large quantities of tremolite (32). Thus, the lung has the ability to concentrate tremolite, and to what extent effects ascribed in animal studies to chrysotile are really effects of tremolite is unclear (51, 53, 54).

Review of the animal investigations indicates that although there are few such studies specifically examining the effects of tremolite, it is clear that tremolite produces mesotheliomas and carcinomas in experimental animals and that it is a powerful mesothelial carcinogen in these test systems. There do not appear to be any data in the literature that specifically inform in regard to biologic effect differences of tremolite cleavage fragments compared with asbestiform tremolite, but it is worth noting that tremolite does appear to be carcinogenic in animals when exposure has been to a mix of particles that includes a substantial proportion of *relatively* short and broad fiber. Considerably more work is needed to determine if the concept of cleavage fragments as biologically different from asbestiform fragments is valid,

Occupational Safety and Health Administration

In June 1986, OSHA promulgated revised standards for occupational exposure to asbestos in general industry and in construction. In both of these revised standards, asbestos is defined to include chrysotile, amosite, crocidolite, actinolite asbestos, tremolite asbestos, and anthophyllite asbestos. The revised standards recognize that actinolite, tremolite, and anthophyllite occur in both asbestiform and nonasbestiform habits. Although OSHA recognized the occurrence of mineralogically distinct nonasbestiform habits for these three minerals, the language of the new standards clearly indicated that exposure to these minerals in their nonasbestiform habits will be regulated in the same way as exposure to "true asbestos." The resulting controversy caused a delay in the implementation of the relevant portions of the revised asbestos standards (a stay of the new regulation as it pertains to nonasbestiform tremolite, anthophyllite, and actinolite was extended to November 1990).

Historically, exposure to the minerals considered to be asbestos by OSHA is determined by the number of fibers larger than 5 μm in length counted per cubic centimeter of air in a workplace using optical (phase contrast) microscopy. A greater than 3:1 length-to-diameter, or aspect, ratio is used by OSHA to distinguish a fiber from other particles in a filtered sample of workplace air. The use of this specific aspect ratio is empiric (although supported by both ACGIH and NIOSH) and is not a universally accepted mineralogic criterion. Mineralogists consider mineral fibers as crystalline units that appear to have grown individually in an elongated shape resembling that of organic fibers (55). So-called cleavage fragments can be produced by breakage of crystals parallel to their faces (55, 56). Cleavage fragments of minerals like actinolite, tremolite, and anthophyllite may resemble organic fibers and may meet the OSHA definitions of a fiber (i.e., are larger than 5 μm in length and have a greater than 3:1 aspect ratio). Such cleavage fragments are described by terms such as elongated, acicular, and fibrous but are not considered true asbestos fibers by many mineralogists (55-57).

The term "asbestiform" has not been previously defined for regulatory purposes. OSHA considers asbestiform fibers to be "crystals that grow naturally as long, flexible, durable fibers. . . ." These fibers are found in bundles that can be easily separated into smaller fibers or fibrils and, during processing, still maintain their same surface properties and activities. Campbell and associates (56) and Wylie and colleagues (57) have proposed definitional criteria for asbestiform particulates that are much more exclusive than the current OSHA regulatory language. They would restrict the term asbestiform to include only those particles larger than 5 μm in length, smaller than 5 μm in diameter, with a greater than 20:1 aspect ratio, and with two or more of the following population characteristics: parallel fibers occurring in bundles; fiber bundles with splayed ends; fibers in the form of thin needles; knotted masses of individual fibers; and fibers showing curvature.

A notice of proposed supplemental rulemaking was published in the Federal Register on February 12, 1990. In it, OSHA proposes to lift the administrative stay and amend the revised asbestos standards to remove nonasbestiform tremolite, anthophyllite, and actinolite from their scope, i.e., not regulate these minerals in the same way as asbestos. In discussing the mineralogic issues, OSHA points out that whether or not these minerals are "asbestiform" depends not on their crystalline structure but rather on the manner of *crystal growth* or the mineral habit. They agree that "there is mineralogic terminology which identifies, at a gross level, distinct and different mineral habits. However, at the microscopic level, for small discrete particles, such as those collected on air monitoring filters, these distinctions become less clear." In discussing the health effects data, the agency points out that it has generally not been possible to distinguish clearly between exposures to asbestiform and nonasbestiform minerals -- both were most likely to have been in the exposure mix.

The agency invited public comment on this proposed action and alternative regulatory approaches. It seems clear, from its discussion of the mineralogic and biologic effect issues, that OSHA is far from convinced that current scientific knowledge supports its proposed rulemaking. They do concede, however, that human and animal data are not "sufficiently supportive" to conclude that the risks are similar in "type and magnitude" for both asbestiform and nonasbestiform minerals.

Review of several critiques (e.g., 58) of the human and animal studies that provide much of the data base for assessing the toxicity of the noncommercial amphiboles prompts concern over how well the mineralogic definition of what constitutes "true asbestos fibers" can be quantified for regulatory purposes. Often in these critiques, the emphasis is primarily on precise mineralogic terminology rather than biologic effect. If the mechanism(s) of asbestos-induced or promoted carcinogenesis was clearly understood, in both mineralogic and biologic terms, then we could proceed easily to distinguish what is truly asbestiform and nonasbestiform for regulatory purposes. However, because such clarity of understanding is not apparent, it would seem prudent public health policy to use an inclusive, rather than an exclusive, definition of asbestos. The primary issue is not so much what is or is not an asbestos fiber in mineralogic terms; rather, it is which particle dimensions are carcinogenic and which are not. A secondary issue is whether particle surface characteristics are important in predicting carcinogenic potential.

Conclusions

1. Unquestioned health effects of tremolite asbestos have been demonstrated in both humans and animals. These effects are identical to those produced by other forms of asbestos.

2. There may be important physicochemical distinctions between asbestiform and nonasbestiform tremolite dust particles. However, there appears to be considerable controversy in applying these mineralogic definitions to specific samples of mineral, particularly individual particles viewed microscopically after collection by air sampling or found in human lung or when used experimentally.

3. The evidence for biologic effect distinctions based on mineralogic parameters, other than fiber dimension and fiber number, is currently inadequate.

4. At present, the prudent public health policy course is to regard appropriately sized tremolite "fibers," in sufficient exposure dose (concentration and duration), as capable of producing the recognized asbestos-related diseases, and they should be regulated accordingly.

5. Despite the recognition of the practical problems involved, there should be further research on the possible biologic implications of any widely accepted mineralogic distinctions and on whether the "regulatory fiber" definition-aspect ratio greater than 3:1, greater than 5 μm in length- should be modified to better reflect biologic effect information.

This statement was prepared by a subcommittee of the ATS Scientific Assembly on Environmental and Occupational Health. Members of the committee are:

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