EPIDEMIOLOGIC STUDIES OF MINING POPULATIONS EXPOSED TO NON-ASBESTIFORM AMPHIBOLES

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EXECUTIVE SUMMARY

Four mining areas have been identified in which the ore bodies have been shown to contain cummingtonite-grunerite, actinolite, or anthophyllite in acicular fragments which meet the dimensional requirements for classification by regulatory agencies as asbestos but which are nonasbestiform. These are (1) taconite mines in the eastern end of the Mesabi Range in Minnesota; (2) the Homestake gold mine in western South Dakota; (3) the Sydvaranger iron mine in northern Norway; and (4) the Wabush Iron Formation in southwestern Labrador: Mineralogic analyses and environmental studies have confirmed that in each of these areas there have been opportunities for significant exposures to non-asbestiform amphibole particles with aspect-ratios greater than 3:1. In no case has there been evidence of an asbestos-like effect on the health of the miners based on (1) historical-prospective cohort studies of mortality in the Minnesota and South Dakota mines, as well as clinical observation in Minnesota; (2) clinical studies, cancer registry observations and a county-wide study in Norway; and (3) radiographic studies in Labrador. While continued observation of these populations is recommended, there is no indication of a need to regulate the non-asbestiform analogs of asbestiform minerals to the same degree or in the same manner as asbestos.

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INTRODUCTION

Regulatory agencies in the United States define fibers as particles with length-to-width (aspect) ratios of 3:1 or more. This definition, with the qualification that such particles be at least 5 micrometers in length, is used in most current asbestos standards when applied to chrysotile and to five amphiboles: amosite (asbestiform grunerite), crocidolite (asbestiform riebeckite), tremolite asbestos, actinolite asbestos, and anthophyllite asbestos. Although tremolite, actinolite and anthophyllite can occur in both asbestiform and non-asbestiform habit, cleavage fragments of these amphiboles often meet the dimensional requirements of the fiber definition even though they are clearly not asbestiform (Campbell et al, 1979; Zoltai, 1979; Zoltai & Wylie, 1979; Ross et al, 1984; Thompson, 1984; Wylie et al, 1985). OSHA is the only regulatory agency which specifically regulates the non-asbestiform varieties of tremolite, actinolite and anthophyllite (OSHA, 1986).

Studies of the health effects of naturally occuring fibrous minerals have nearly all involved populations exposed to commercial asbestos, where the presence of asbestiform particles was unquestioned. There is thus relatively little published evidence bearing directly upon the pathogenicity of elongated but non-asbestiform amphiboles.

Review of the literature has, however, yielded a few studies of populations where exposures to nonasbestiform amphiboles occurred. In each instance the study was initiated because of concern based on the

putative presence of asbestiform particles, and in each instance more careful mineralogic appraisal indicated that the exposures were predominantly nonasbestiform. These populations are (1) miners and millers of taconite in Minnesota; (2) employees of the Homestake gold mine in Lead, South Dakota; (3) employees of the Sydvaranger iron mine in northern Norway; and (4) iron miners in the Wabush area in Labrador. Available information on the types and levels of exposures and on health effects will be summarized in this report.

It is difficult to be entirely consistent in use of the terms fiber, fibrous, asbestiform, and asbestos because of differing information supplied by different authors. The term fiber should be limited to elongated particles which resemble organic fibers in having parallel sides and relatively high aspect-ratios. As pointed out earlier, a 3:1 aspect-ratio has become the lower limit used by regulatory agencies even though not based on demonstrated health effects. By light microscopy some acicular cleavage fragments may appear fibrous and be mistakenly called asbestiform. However, a fiber is not asbestiform unless it has special characteristics including not only a very high aspect-ratio, but also separability into fine fibrils, flexibility, and high tensile strength (Zoltai, 1979). All forms of commercial asbestos are made up of asbestiform fibers, but other minerals can occur in similar habits. Even though other minerals may occur in asbestiform particles only the six that have been used commercially can properly be classified as asbestos and then only when they are asbestiform.

TACONITE WORKERS IN MINNESOTA

History. The term "taconite" was first applied to a hard, fine-grained iron-containing rock found in the Mesabi Range of Minnesota, but has since been extended to similar formations in other parts of the world. After World War 11, as higher-grade iron ores were depleted and economically feasible methods for the beneficiation of 1ower-grade taconite became avai1able, the Minnesota deposits became a major source of iron for the U.S. steel industry. The Reserve Mining Company began pilot operations in 1952 with its full scale operation starting in 1955. Erie Mining Company operated a pilot plant from 1948 to 1952 with full scale operations beginning in 1958. U.S. Steel's pilot plant began in 1953 with its Minntac mine and mill opening in 1967.

The discovery in 1972 of "asbestos-like" particles in the water supply of Duluth, Minnesota, set in motion a great deal of legal, regulatory, and scientific activity (Masson et al, 1974; Champness et al 1976; Kramer 1976; Langer et al 1979). The particles were described as cummingtonite-grunerite fibers resembling commercial amosite. Tailings from the Reserve mine discharged into Lake Superior about 50 miles northeast of Duluth contained such particles and were considered the probable source of the Contamination. Studies of the health of residents of Duluth were initiated (e.g. Levy et al, 1976; Sigurdson, 1977, 1981). Employees of taconite mining companies also came under investigation.

Mineralogy. Gundersen and Schwartz (1962) described in detail the geology of the Biwabik Iron Formation in the eastern Mesabi District,

where the **Reserve** and **Erie** mining operations are located. They reported the presence in some areas of cummingtonite, actinolite, and riebeckite (traces). There were other amphiboles, such as hornblende, which are not included in the asbestos regulatory definitions, but which sometimes produce fibrous particles. They stated that "amphiboles, particularly cummingtonite, actinolite, hornblende, and hornblende-cummingtonite, constitute the dominant mineral family in the eastern Mesabi Range. Minute amounts of riebeckite also occur. With the exception of quartz, cummingtonite is the most abundant silicate in the metamorphosed iron formation." No tremolite was found. Their geologic description did not specifically refer to the size characteristics of the amphiboles, but there were references to the presence of acicular cummingtonite and acicular taconite. They did not find any fibrous riebeckite, i.e. crocidolite, but they stated that one observer had reported this in one area. In summary, this report confirms the widespread occurrence of actinolite and cummingtonite in the eastern Mesabi District, often in acicular particles, but gave no indication that any occurred in an asbestiform habit.

The foregoing findings are confirmed in two more recent reports by Bonnichsen (1969, 1972)*. The former stated that the principal minerals in the formation of the Reserve mine and the eastern Erie mine (the Dunka pit) are quartz, magnetite, orthopyroxene, Ca-pyroxene, fayalite, cummingtonite and hornblende. The author grouped actinolite and ferroactinolite with hornblende. The presence of acicular cummingtonite and acicular ferroactinolite is mentioned. Bonnichsen's 1972 report essentially repeats the information given in the 1969 report; however, what was previously referred to as cummingtonite is now categorized as

cummingtonite-grunerite. This is consistent with uncertainties in the literature as to the precise differentiation of cummingtonite and grunerite, both being iron-magnesium silicates.

The foregoing geologic reviews were directed toward defining mineral species as they related to their location in the Mesabi Range and their geologic history, rather than characterizing mineral particles as they might relate to health effects or regulatory action. More recent studies have addressed these questions. 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 should not be referred to as asbestiform. Langer et al (1979) in a review of contamination of Lake Superior with amphiboles, came to the same general conclusion, though not dismissing the possibility that the nonasbestiform particles might have health effects. Langer reaffirmed this in an editorial (1981) in which he stated that the issue in the Reserve Mining case was "the biological activity of acicular (needle-like) cleavage fragments of grunerite, one of the amphibole gangue minerals, which on the basis of the best available analytical techniques for studying submicroscopic particles, could not be distinguished from asbestiform (fibrous) grunerite from South Africa (amosite)."

Rebecca West of **NIOSH** in 1982 prepared a brief report summarizing analyses of bulk samples and airborne dust from Mesabi Range taconite mines and mills. Although cummingtonite-grunerite had been described as the predominant silicate in the formation, it was notable that analyses of the bulk samples did not report **cummingtonite-grunerite**, nor were there references to actinolite or ferroactinolite. In 19 bulk samples

from 4 operations, 16 were reported as showing elongated particles, i.e. particles with aspect ratios 3:1 or greater, but "only a few of the hornblende species were true asbestiform fibers; the rest were rod-shaped particulates." Of 28 air samples, 17 were collected on nucleopore filters. All of the latter contained "fibrous" particles, but all were rod-shaped rather than asbestiform; all but three were under 5 um in length, and none was reported as being cummingtonite-grunerite or actinolite. In eleven samples collected on AA filters representing environmental air samples, five showed "fibrous" particles. Only three of 74 such particles, described as olivine, were reported as asbestiform, and all of these were under 5 um in length. Phase ccntrast microscopy of the AA samples reported "fibers" in six samples in concentrations of 0.009 to 0.267 f/cm^3. The foregoing report would not indicate any detectable exposure to actinolite or cummingtonite-grunerite based on the small samples studied.

Steven Ring of the Minnesota Department of Health, in 1981 reported analyses of tailing samples from taconite processing plants, collected between September 5, 1980 and March 19, 1981. They were analyzed for mineral fibers by transmission electron microscopy (TEM). Samples from Reserve Mining Company at the extreme eastern end of the Range contained grunerite, actinolite, quartz and magnetite. In Erie Mining Company samples, of 44 elongated particles identified, 24 were cummingtonite-grunerite, olivine, or minnesotaite, one was hornblende, one ferroactinolite, and 14 were unidentified or ambiguous, Only one, of unknown type, was over 5 um in length. In U.S. Steel's Minntac mine, 40 such elongated particles were reported, the longest being 2.78 um in

length. Of these, 5 were nonsilicate, 2 were hornblende, 3 ambiguous, 10 cummingtonite-grunerite, one quartz, 19 no data or ambiguous.

Virta et al (1983) from the U.S. Bureau of Mines, included a sample from the Peter Mitchell pit of the Reserve Mining Company in a comparison of the size characteristics of amphibole particles from different sources. The Peter Mitchell sample, reported to contain cummingtonite, hornblende and actinolite, was clearly distinguishable from samples of commercial cummingtonite-grunerite (amosite) obtained from a shipyard and an electric company. Only 8%of the Peter Mitchell particles had aspect ratios of 10:1 or more (compared with 72% and 83% for the samples from commercial asbestos operations) and closely resembled those from the Homestake Gold Mine and from a crushed stone operation, in terms of average length, diameter and aspect-ratios.

Sheehy (1986) studied dust exposure data from six Minnesota taconite mines and processing plants based largely on over 16,000 analyses of samples collected by the plants between 1956 and 1984 to measure silica-containing dust. Since these involved both midget impinger dust counts and respirable mass data, a conversion factor of 0.1 mg/m^3 = 1 mppcf was used (Sheehy and McJilton, 1987). Although there was no attempt to quantitate amphiboles, this report provides useful information on dust levels which serve as indirect indicators of probable amphibole exposures.

Plants were not named by Sheehy with respect to individual dust levels, but dates and types of operations are reported, so they could be identified by a knowledgable reader. It is not necessary to review the data in detail, however. The report includes comparisons between different laboratories, different time periods and different

meteorological conditions, among other factors. In general, geometric mean dust levels were below 0.5 mg/m^3, but in a few areas, notably coarse and fine crushing and concentrating areas, they sometimes exceeded 1 mg/m^3. Levels were also sometimes above 1.0 mg/m^3 in the pelletizing areas but here quartz and amphibole concentrations would have been low. To put the concentrations in perspective, it should be pointed out that a time-weighted average exposure of 1.0 mg/m^3 would have been equivalent to the OSHA and MSHA quartz standard for any dust containing 8% quartz. Although not providing quantitative information on amphibole exposures, these results suggest that there could have been significant amphibole exposures to some workers in the crushing and concentrating areas.

Coffin et al (1982) demonstrated that a sample of ferroactinolite obtained from surface rock in the Mesabi iron-formation produced tumors in rats both by intratracheal instillation and intrapleural injection. The particles which were classified as fibers ranged in aspect-ratio from 3 to 130 (mean 9, median 6), and in length from 0.3 to 52.5 um (mean 3.18, median 1.5). After studying the size distribution of ferroactinolite particles in rat lungs at successive intervals after instillation, Cook et al (1982) concluded that the strong carcinogenicity of the ferroactinolite was probably related to *in vivo* longitudinal splitting to produce large numbers of very long thin particles. Thus the ferroactinolite which was tested appears to have been asbestiform. This does not appear to be a widespread characteristic of the iron-formation amphiboles, however, and is not reflected in any available information on worker exposures.

In summary, despite some differences in terminology, there is general agreement among all observers that the taconite ore body in the eastern Mesabi Range (1) contains amphiboles, notably cummingtonite, grunerite, actinolite and horneblende; (2) that cleavage fragments of these minerals meet the regulatory definition for "fibers", and (3) that true asbestiform varieties are rarely found.

Epidemiologic studies in Minnesota. As pointed out earlier, concern about contamination of Lake Superior from taconite tailings was first related to possible effects on community water supplies. To date, no studies have indicated that there is any increased incidence of gastro-intestinal or other malignancies resulting from this (Levy et al, 1976; Sigurdson, 1977, 1981). Since there is no indication that any form of ingested asbestos causes disease, these negative studies have no evidential value as to the potential dangers from non-asbestifom amphiboles when inhaled.

Worker health and mortality in the taconite mines and mills have provided more useful data. Clark et al (1980) studied employees of Reserve Mining Company to ascertain if there were symptoms, radiographic changes or reductions of pulmonary function that might suggest asbestos-related disease. They compared 249 men who had been exposed to taconite dust for 20 or more years with 86 men who had not had such exposures. No cases of definite interstitial fibrosis, ill-defined diaphragm, pleural calcification or mesothelioma were found. They concluded that (1) cigarette smoking was correlated with bronchitic symptoms and impaired respiratory functions; (2) taconite workers were at risk of silicosis; and (3) there was no evidence for an asbestos effect.

in 1981 Higgins et al reported a comprehensive study of Reserve employees, including an analysis of mortality through 6/30/76 of 5,271 men who had worked for more than one year between Jan. 1, 1952 and July 1, 1976. The report showed no apparent effect of taconite exposures on mortality. There were 15 deaths from respiratory cancer with 17.94 expected (based on Minnesota death rates), and 20 cases of digestive cancer with 17.57 expected. However there were only 30 deaths which occured 20 or more years after hire, so the authors did not feel that conclusions could be drawn for diseases with long latency. Small opacities consistent with pneumoconiosis were found in a few chest radiographs (1% had ILO classifications of 1/1 or higher). Only one was an ILO category 2, and review of this case ruled out occupational exposure as a cause. The authors did not feel that there was any evidence of a serious dust effect but recommended continued radiographic followup, with reference to silica.

Higgins et al stated that "Unfortunately measures of fiber concentrations were *not* extensive enough to be used." They did report however that fiber "concentrations greater that 0.5 f/ml were occasionally observed, mainly in the crushing department, but none approached the threshold limit value of two fibers per ml" (Higgins et al, 1983). They developed silica exposure indices based on twice-yearly dust surveys which had been carried out by the Trudeau Institute beginning in 1956. Until 1975 midget impinger counts were used; thereafter analyses were gravimetric. Most samples were collected over 4- or 8-hour periods so that they approximated time-weighted averages rather than ceilings. Total dustiness was greatest in mining, coarse crushing, fine crushing and pelletizing areas. However, the quartz

concentrations were lower in pelletizing. Of 5,751 men who had worked for at least one year, 2,056 had worked at some time in an area where dust exposures were in a "high" range, i.e. 0.49 to 1.29 mg/m^3; 2,032 men had at some time worked with silica exposures as high as 0.063-0.231 mg/m^3. These figures would suggest that many employees were exposed to quartz concentrations at or above current ACGIH recommended concentrations of 0.1 mg/m^3. Since the non-quartz portion of the respirable dust had a high amphibole content, one can infer appreciable exposures to these minerals, which is consistent with the limited data available on fiber concentrations.

A shorter report of the study by Higgins et al was published in 1983, with the same conclusion, i.e. that there was no suggestion of increased mortality associated with working in the Reserve Mining Company. There appeared to be no association between mortality and exposure to dust. In 5,751 men who had worked in the mine for one year or more, there were 15 lung cancer deaths with 17.9 expected (SMR=84). During observation 15 or more years after employment the SMR for lung cancer was 102. There were no mesotheliomas. However they urged caution in reaching final conclusions. Exposures to total dust, silica dust, and fibers had been relatively low, and the average time from hire to the end of observation for the group was only 14.7 years, with none over 24.6 years. It would clearly be desirable to update this study; 11 years have elapsed since its conclusion.

There have been two analyses *of* mortality in the taconite miners employed by Erie Mining Company and U.S. Steel in the eastern portion of the Mesabi Range. Erie operates two mines; one ore body (the Dunka pit) has amphiboles similar to those in most of the Reserve operations, the

other, which on the average provides about 60% of the final ore mix, has fewer amphiboles. The Minntac mine, somewhat farther west, contains much less cummingtonite-grunerite, but definitely contains amphiboles.

A 1984 report (Cooper, 1984) reported mortality from 1959 through 1977 in 3,444 men employed at least 3 months in taconite-exposed jobs prior to January 1, 1959. There were no excess deaths from lung cancer or non-malignant respiratory disease.

An update of the foregoing study was completed in 1986 (Cooper, Wong and Graebner, 1986) and is due to be published in the Journal of Occupational Medicine in 1988. The cohort of 3,444 men was observed for an additional 5 years, through December 31, 1983. There were 801 total deaths during 86,307 person-years of observation. There were only 38 deaths from lung cancer, with 54.3 expected, for an SMR of 59 (based on U.S. rates). When Minnesota death rates were used for comparison the SMR for respiratory tract cancer was 85. There were small but not statistically significant excess deaths from kidney and lymphatic cancer but no excess deaths from non-malignant respiratory disease. There was one death from mesothelioma; this worker's exposures to taconite mining had begun only 11 years before death and he had had previous employment for many years as a locomotive fireman and engineer, with potential exposures to asbestos.

The Erie and Minntac populations had had ample opportunity to develop diseases with long latency, since there had been 12,420 person-years of observation 20 or more years after hire, with 221 deaths. It therefore provides strong evidence against there being a cancer hazard associated with these taconite mining operations. Unfortunately it is impossible to quantitate exposures to amphiboles.

inasmuch as they are predominant minerals in the ore body, one can infer that there would have been repeated exposures, similar to those to quartz, particularly in crushing and concentrating operations.

HOMESTAKE GOLD MINE STUDIES

History. During legal proceedings aimed at limiting the discharge of tailings from the Reserve mine into Lake Superior, it was pointed out that another U.S. mine was known to handle ore which contained cummingtonite-grunerite, the amphibole reported as present in the Mesabi Range. This was the Homestake gold mine, near Lead, South Dakota, where geologic and mineralogic reports had shown cummingtonite-grunerite to be present (Noble and Harder, 1948; Noble, 1950). It was pointed out that the Homestake operation had begun in 1876, in contrast with the Reserve Mining Company, which dated back only to the mid 1950's. This opportunity to detect asbestos-related disease with long latency prompted studies by NIOSH and by Homestake.

Homestake exposures. The early geologic reports by Noble and Harder (1948) and Noble (1950) had pointed out the presence of amphiboles in the cummingtonite-grunerite series, but without reference to asbestiform or fibrous habit. There was a survey of the Homestake Mine in 1974 by the Mining Enforcement and Safety Administration (MESA) (Bank et al, 1974), to obtain information on fiber exposures. Fibers interpreted as being cummingtonite were observed, but all time-weighted average concentrations were below the asbestos standard of 2 f/cm^3. Individual short-term concentrations of 2.7, 3.2. and 4.1 f/cm^3 were measured in three locations. It was stated that, "The fibers observed

in the Homestake Mine airborne dust were of the acicular or needle-like type plus lath-like fragments. These fibers and laths were probably cummingtonite, although specific identifications could not be made."

MESA also observed in its 1974 survey that there was arsenic, in the form of arsenopyrite, in the ore body, and that in some locations, airborne silica exceeded the threshold limit value. NIOSH utilized data from this 1974 survey in its 1976 reports.

The first quantitative and detailed description of exposures to amphiboles in the Homestake mine were those included in reports by NIOSH (Gillam et al, 1976; Dement et al, 1976). The initial report emphasized similarities between Homestake and Reserve exposures to cummingtonite-grunerite. The analyses were based on 200 air samples which had been collected by MESA in 1974. Average "fiber" concentrations in airborne dust had been found to be 0.25 fibers/cc (using phase contrast miscroscopy [PCM] and counting all particles with greater than 3:1 aspect ratios and lengths of 5 um or more). The highest single airborne concentration had been 2.8 f/cc. NIOSH studied 25 of these samples by electron microscopy (TEM) and x-ray diffraction. They concluded that 80-90% of the fibers were amphiboles, 60-70% being grunerite, 1-2% cummingtonite, and 10-15% fibrous hornblende. About 20% could not be identified. Average total "fiber" concentrations, based on TEM, were 4.82 f/cm^3. However, for those greater than 5 um in length, the average concentration by TEM was only 0.36 f/cm^3. Based on 211 particles, the median diameter was 0.13 um and the median length was 1.10 um. This contrasted with NIOSH studies of the amosite exposures of pipe insulators, where the median length had been 4.9 um with 51% of fibers being longer than 5 um. The amphibole particles shown in a

photograph in the NIOSH reports (Cement et al, 1976), based on settled dust at Homestake, appeared to be cleavage fragments. In their 1976 report, Gillam et al minimized the possible importance of quartz exposures, stating that there was no evidence that these had ever exceeded OSHA standards, even though the ore contained as much as 39% free silica, and respirable dust collected in 1973 had 13.1% quartz.

As will be pointed out later when the epidemiologic results at Homestake are summarized, NIOSH investigators in 1976 interpreted the results as indicating that non-asbestiform cummingtonite-grunerite particles, most of which were under 5 um in length, had caused excess lung cancers as well as asbestosis. This supported a position that, by analogy, the situation at the Reserve mine was hazardous and also that asbestos standards should be drastically revised to include short fibers.

Zoltai and Stout (1976) compared the cummingtonite-grunerite minerals in the Homestake mine with those in the Peter Mitchell pit in Minnesota and concluded that they were similar in crystal structure and chemical composition. Although they were cleavage fragments and not asbestiform, they felt their biologic effects could only be determined by animal tests and epidemiologic studies, not by assumptions based on mineralogic analogies.

In a subsequent environmental study of the Homestake Mine, carried out by NIOSH in 1977 and reported in 1981 (Zumwalde et al, 1981), the matter of fiber exposures was again addressed. Although marred by many inaccuracies in mineralogic terminology, the report contains useful information. A total of 448 personal samples were studied for fibers. A fiber was defined as any particle which had a length-to-diameter ratio

of 3:1 or greater and which was longer than 5 um. Based on phase contrast microscopy, it was reported that 5 of 96 underground workers and 4 of 12 surface workers had time-weighted average (TWA) exposures over 2.0 f/cm^3, the highest being 3.01 f/cm^3. Mean exposures of underground miners were reported as 0.63 f/cm^3; that of underground non-miners 0.55 f/cm^3. Surface workers in crushing operations had TWA exposures of 1.72 f/cm^3.

Fifty-one of the samples were studied by transmission electron microscopy and electron diffraction; for this purpose there was equal representation of samples above and below concentrations of 2 f/cm^3. They were classified in 4 categories: (1) cummingtonite-grunerite (incorrectly stated as synonymous with "asbestos amphibole"); (2) tremolite-actinolite (stated as synonymous with "asbestos amphibole"); (3) hornblende; and (4) ambiguous or nonasbestos, It was reported that 84% of the airborne fibers were amphiboles and about 16% ambiguous or nonasbestos; of the amphiboles 69% were cummingtonite-grunerite; 15% tremolite-actinolite, and 16% fibrous hornblende. Dimensions, expressed as geometric means, were reported as follows: cummingtonite-grunerite, diameter 0.43 um, length 3.3 um; tremolite-actinolite, diameter 0.27 um and length 4.1 um, all fibers combined, diameter 0.4 um and length 3.2 um. Of the cummingtonite-grunerite "fibers", 24% were over 5 um in length, while 32% of the tremolite-actinolite were > 5 um. For all particles analyzed by TEM and called fibers, they reported that 33% had

aspect-ratios over 10:1 regardless of length (Table I),

Table I. **Fiber size distribution by aspect ratio (length to diameter) electron microscopy analysis at 17,000X magnification of airborne samples collected at the Homestake Gold Mine, Lead, South Dakota.** *

Types fibrous mineral	Cummulative frequency (%)		
	≥10:1	≥5:1	≥3:1
Cummingtonite-Grunerite	30	77	100
Tremolite-Actinolite	68	92	100
kornblends	19	74	100
Ambiguous Determination or Non-Asbestos	26	83	100
Total	33	79	100

*Copied from Zumwalde et al (1981), table 20.

Although the author stated that bulk samples of ore were analyzed for fibers, using TEM, no details were given in the lists. They were summarized on page 57 as confirming "the types of fibers observed in the airborne sample exposure data collected in both the mine and mill".

The NIOSH report published in 1981 is consistent with the earlier report in reporting cummingtonite-grunerite as the predominant mineral occurring in "fibrous" form based on aspect-ratios of 3:1 or more. However, it identifies a significant amount of tremolite-actinolite not

mentioned by Dement et a? (1976). The average exposures reported by optical microscopy were somewhat higher than reported earlier, ranging from 0.55 f/cm^3 to 1.72 f/cm^3 in selected subgroups, compared with an overall average of 0.25 f/cm^3 reported earlier. The highest concentrations reported were in the same range, i.e. 3.0 f/cm^3 compared with 2.8 f/cm^3. A major difference in the two reports relates to "fiber" length. In 1976 it was stated that 94% of airborne "fibers" were under 5 um in length. In 1981, on the other hand, only 77% of all "fibers" were under 5 um in length. The percentages for cumingtonite-grunerite and tremolite-actinolite were given as 76% and 68% respectively, for "fibers" less than 5 um in length.

The 1981 report (page 73) addressed the question of whether or not the cummingtonite-grunerite particles that were seen at Homestake were actually similar to commercial amosite. After pointing out that two NIOSH studies involving exposures to commercial amosite had shown particles with characteristics quite different from those seen in the Homestake cummingtonite-grunerite, it was stated that "the type of amosite used by the workers in these two studies, which is typically found in other industrial applications, is considered fibrous both in a macroscopic and microscopic scale. This differs from the amosite observed in the Homestake Gold Mine since it (i.e. the latter) forms in a nonfibrous mineral habit, but through attrition by the various mining processes, fragments into respirable fibers. Most of these fibers, as demonstrated by the electron microscopy characterization, are identical (sic) to airborne fibers observed in the industria? environment."

Later, on page 73, it is stated that, "When the Homestake fiber size data ... are compared to the fiber dimensional characteristics

which are thought to produce biological responses in animals, only the small diameter fibers (less than 1.5 um) appear to match the criteria. Most of the observed fibers had lengths less than 5.0 um and, when compared to the animal study results, they would be considered to have a lesser potential for creating a biological response." This is followed by a discussion that some studies in animals had suggested high retention of smaller fibers.

Virta et al (1983) did sire- and shape-analyses of particles in air samples from Homestake, which they had received from MSHA or OSHA. The predominant mineral was described as being cummingtonite, apparently based on Noble's earlier characterization. Only 4% of the airborne amphibole particles (11 of 365) had aspect-ratios of 10:1 or greater, the mean length was 4.6 um and the mean width 1.1 um. These were similar to the dimensions they reported for the Peter Mitchell pit (taconite ore) sample and were quite different from those found in industrial operations using amosite.

In summary, there appears to be general agreement that the ore body in the Homestake Gold Mine contains cummingtonite-grunerite, tremolite-actinolite, and hornblende and that all of these are found in elongated, but non-asbestiform particles. Although levels of exposure to these so-called fibers have not been quantitated until recently, the high percentage in the ore and the available data on past quartz exposures suggest that they were sufficient to have produced asbestosis or other asbestos-related diseases if they had had the characteristics of commercial amosite.

Epidemiologic studies. The first epidemiologic study of the Homestake population was that reported in 1975 by Gillam et al and

published in 1976. It was based on a population of 439 individuals who had been examined by the U.S. Public Health Service in a 1960 silicosis survey, who had been employed at least 60 months underground at Homestake, and who had never mined underground elsewhere. Actually, as pointed out later by Swent et al(1976), these criteria were not followed closely. Some study participants had not worked underground and others had been previously employed in other underground mines. The population was followed from April, 1960 through December 31, 1973. There was a total of 70 deaths, with 52.9 expected based on South Dakota rates. There were 10 respiratory malignancies reported, with 2.7 expected ($p < 0.01$), and 8 nonrespiratory malignancies with 3.2 expected ($p < 0.05$). Also, there were 8 deaths from nonmalignant respiratory disease, with 3.2 expected ($p < 0.05$). The authors concluded that, "the observed excess of malignant respiratory disease can therefore be attributed to asbestos, singly or in combination with cigarette smoke, and that of non-malignant respiratory disease can therefore be ascribed to asbestos, with a possible additive role from low exposure to free silica dust."

Although often quoted, the foregoing conclusions have not been confirmed by later studies of Homestake miners. As Swent et al pointed out in a 1976 commentary, it could be demonstrated that many members of the cohort had worked in other underground mines before joining Homestake. Also there was evidence to show that their smoking histories were not "far less than those of underground uranium miners", as stated by NIOSH. Most of the cases of nonmalignant respiratory disease interpreted by NIOSH as asbestosis had been clearly classified as silicosis on death certificates, and in many cases autopsies had been performed. NIOSH ignored documented evidence that exposures to free

silica in the past had been well above standards and adequate to explain the observed cases of pneumoconiosis. There were a number of other inherent flaws in design, execution and reporting. It was therefore essential to carry out additional studies of the Homestake workforce.

McDonald et al in 1978 reported an analysis of mortality in 1,321 male employees who were members of the Homestake Veterans Association, which was limited to employees who had had 21 years service with the company. In the period 1937 through 1975 there were 631 deaths with 549.7 expected, for an SMR of 115. There were 17 respiratory cancers with 16.5 expected for an SMR of 103, 37 deaths from pneumoconiosis with none expected, and 39 deaths from respiratory tuberculosis, including silicotuberculosis, for an SMR of 1,083. The authors concluded that the mortality pattern was consistent with that of a population which in the past had had a high silicosis risk, but that there was no evidence to suggest an asbestos disease pattern. A single mesothelioma was observed, in a surface worker who, during a relevant time period (22 to 26 years before death) had worked in machine maintenance with possible asbestos exposures.

NIOSH has more recently completed a large scale retrospective cohort mortality study of 3,328 underground miners at Homestake (Brown et al, 1985a, 1985b). They described cummingtonite-grunerite, silica, arsenic (arsenopyrite) and radon daughters as possible hazards. The cummingtonite-grunerite "fibers" found in airborne samples were relatively short (geometric mean length 3.3 um). In 1977 the geometric mean TWA exposure for all miners to such particles over 5 um in length was 0.44 f/cm^3. They pointed out that since dust levels in the past had been higher, the past exposures to these particles had also probably

been higher. For example, historical data showed that prior to 1952, exposure to free silica had generally been above accepted levels. They found no association between exposures in the underground gold mine workers and lung cancer (43 observed with 42.9 expected). Silica exposures, however, were strongly associated with mortality due to respiratory tuberculosis, mostly silicotuberculosis (36 observed with 9.9 expected), and with nonmalignant respiratory disease, mostly silicosis (53 observed with 19 expected). Archer (one of the paper's authors) has expressed his opinion (personal communication to Brown, 1985) that the NIOSH summary overstated the negative results to a moderate extent, by (1) using U.S. national rates for comparison, (2) not stressing the difficulty of diagnosing lung cancer in the presence of silicotuberculosis or silicosis, and (3) ignoring a modest association between lung cancer deaths and potential latency. Nevertheless, it is clear that the major problem in Homestake miners has been silicosis, and that there is insufficient evidence to indicate an amosite-like effect.

STUDIES IN NORWEGIAN IRON MINES

In 1902 iron ore was discovered in an area of northern Norway near the town of Kirkenes, about 3 miles from the Norwegian-Russian frontier. This deposit was described in 1968 as being a true "taconite-quartz-banded-magnetite" similar to that mined in Minnesota. In 1907 development began, and in 1910 the first iron concentrates were produced. The mine is open-pit. When the potential amphibole exposures came to the attention of the American iron ore industry in 1978, the

possibility of exploring the health experience of these Norwegian miners was raised.

Inquiries in 1978 to A.S. Sydvaranger, the corporation which owned the mine, elicited a response that "cummingtonite-grunerite occurs in small quantities in our taconite near Kirkenes. We have however never registered any health problems or other harmful effects which may be connected to these minerals.. We have done no epidemiologic studies of the workers ...."

In 1979 the Director of Labor Inspection of Norway, Dr. Arne Bruusgaard (personal communication to WCC) supplied the following information: although there had been 6 instances of silicosis reported in chest radiographs from the Sydvaranger plant, there had been no evidence of asbestos-type disease. He also pointed out that the Cancer Registry of Norway had reported no mesotheliomas from that area of Norway. A direct inquiry to the Cancer Registry in 1980 showed that since 1953 there had been only 3 mesotheliomas reported from the county of Finnmark, where the Sydvaranger mine was located. None had been in the area where the mine was located.

Gylseth and Norseth (1981) from the Institute of Occupational Health in Oslo reported analyses of airborne dust collected in the mine, which contained up to 1 f/cm^3. They described the presence of cummingtonite-grunerite and hornblende in the dust. Total dust concentrations were as high as 36 mg/m^3 in a crushing plant, with a quartz content of 23-32%. Fiber concentrations ranged from below 0.01 f/cm^3 to 0.3 f/cm^3, except for one sample at 0.9 f/cm^3. Arithmetic mean lengths ranged from 5.4 to 7.6 um and mean aspect-ratios ranged from 7.4-11.4. X-ray diffraction identified the fibers as

hornblende/actinolite, or cummingtonite-grunerite. Although positive separation of actinolite and hornblende was not possible, they inferred that probably most were hornblende. Lung tissue from two workers who had died of lung cancer was found to contain fibers similar to those in the mine dust. They referred to these as "amphibole bodies"; they also found non-amphibole coated particles. As for health effects in the mine employees, they stated that while there had been some increased lung cancer risk in the mine population 15 years earlier, that there was no increased risk at present. No increased relative risk during the years 1949-1963 could be demonstrated. Their conclusion was, "Taking both the exposure level and fiber dimensions into consideration, assuming that fibers longer than 8 um are the most potent particulate carcinogens, we conclude that the present exposure in the mine probably constitutes a minor carcinogenic risk." They thought it of interest however that considerable numbers of fibrous particles were being retained in the lungs of the miners, and that "It cannot be excluded that the fibers have been a contributing factor to the cancer of the two miners."

Saugstad of the Institute of Occupational Health of Norway in 1983 analyzed lung cancer incidence in Finnmark county, which averaged about 50% above the mean for Norway. She concluded that "the mining industry in Sør-Varangeer did not contribute to a higher risk among regularly employed as compared with the never-employed residents in the community". She also suggested that residents of the county as a whole were at relatively high risk due to a heavy smoking pattern (approximately 90% of males smoked), but that there were additional risks near the border possibly due to air pollution from Russian nickel smelters.

In summary, the evidence from Norway strongly suggests that there are elongated, but not necessarily asbestiform, amphiboles in the Sydvaranger ore body with sufficient airborne concentrations in the work area for them to be easily found in the lung tissue. Limited studies do not indicate any evidence of asbestos-related disease.

LABRADOR MINES

Another population known to have had exposures to non-asbestiform amphiboles is iron miners in western Labrador. The two major mines, that of the Iron Ore Company of Canada (IOCC), and the Scully mine (formerly a subsidiary of Erie Mining Company) have been in operation since 1962 and 1965 respectively. During the 1970's, periodic chest films were reported as showing radiographic changes consistent with pneumoconiosis. When it was pointed out that the ore body contained amphibole minerals, including cummingtonite-grunerite, there was immediate concern as to the potential for an asbestos effect. A large scale study (The Labrador West Dust Study) was begun in September, 1979, by the Labrador Institute of Northern Studies, under contract with the government of Newfoundland and Labrador. A detailed report was made available in 1982 (Labrador Inst. of Northern Studies, 1982). Although quartz and iron oxides were the major components in settled and airborne dust, the authors verified the presence of cummingtonite-grunerite minerals, as well as other amphiboles. Study of airborne samples by light microscopy showed low levels of fibrous material in both mines. In IOCC the maximum concentration was 0.3 f/cm^3 with the average being 0.03 f/cm^3. At Scully the maximum was 0.7 f/cm^3, with a mean of 0.1 f/cm^3. Electron microscopy showed that most fibers. i.e. particles with

aspect ratios of 3:1 or more, were oxides of iron and manganese. There were iron-rich amphiboles, presumably cummingtonite-grunerite. Of the fibers, 98.5% were shorter than 5 um. Of the remaining 1.5%, less than 20% were elongated amphibole particles, and even fewer could be regarded as asbestiform. The foregoing analyses were by Dr. Neil Rowlands of McGill University.

Lee et al (1983) agreed that amphiboles in the cummingtonite-grunerite series could be identified in the ore body. One form, Labrador grunerite, was non-fibrous; another was a manganoan cummmingtonite intimately associated with a non-fibrous anthophyllite.

Knight et al (1987) in a report on the size distribution of airborne dust in the Labrador iron mines provided information on respirable dust levels ranging from 0.2 to 4.25 mg/m^3 in 50 samples. They did not, however, refer to amphibole or fiber concentrations.

One can conclude from 'the reports on the composition of the ore and dust in the Labrador mines that miners and ore processors are potentially exposed to quartz, iron oxides and to amphibole minerals. The latter appear to have been almost entirely non-asbestiform, although sometimes occurring as elongated particles.

Medical information has come from the Labrador West study and from a report by Edstrom and Rice in 1982. The former, in its reports released in 1982, stated that chest radiographs were consistent with pneumoconiosis in 32 of 1,946 IOCC employees and in 14 of 499 Scully employees who had worked 3 months or more. Although in the initial detailed reports it was suggested that a large proportion of these individuals had asbestotic patterns, based on the proportion with irregular opacities involving the lower lobes and the presence of

pleural abnormalities, this was not mentioned in the executive summaries. It was not included in the published version of the radiographic findings (Chittai et al, 1982) who described the changes as typical of mixed-dust pneumoconiosis.

Sixty-one films, selected as having been found abnormal, were reviewed in 1982 by Sargent in a report to IOCC. All but 7 films were interpreted as having doubtful or definite radiographic changes consistent with pneumoconiosis, i.e. ILO categories 1/0 or higher; in 56% the classifications were 1/1 or higher. It was felt that the changes were consistent with silicosis, siderosis, or a mixed-dust pneumoconiosis. There were no changes suggestive of asbestosis. The small opacities were predominantly rcund -- round only in 35, irregular only in 5, and mixed in 10. Major involvement was in the upper lung fields. In only 3 films was there' doubtful evidence of pleural thickening and none showed definite thickening. Although consistent with a mixed-dust pneumoconiosis, the radiographic changes were probably largely due to iron oxide, in view of the high concentrations of hematite and magnetite in airborne dust and the rapid appearance of changes (in less than 10 years in most subjects).

There has been no epidemiologic analysis of causes of death in these workers, so one cannot yet compare them with other amphibole-exposed populations. Because there is good mineralogic data available, however, they should provide useful information in the future as to the effects of the mixed 'exposures to quartz, iron oxide, and non-asbestiform amphiboles. The definite evidence of mixed-dust pneumoconiosis supports the occurrence of significant exposures.

DISCUSSION

A crucial issue in reaching agreement on a proper definition of asbestos in health-oriented standards is the pathogenicity of acicular fragments of tremolite, actinolite, and anthophyllite. Although there is no solid evidence to show that these are hazardous, their dimensions may overlap those of asbestiform particles of the same minerals. This has led some to conclude that the prudent course is to regard them as hazardous until proven otherwise. Because unnecessary regulation is wasteful and distorts priorities, it is important to accumulate evidence as promptly as possible to resolve the issue.

Relatively few populations of individuals exposed to non-asbestiform amphiboles have been studied. In this report we have reviewed four of these: taconite miners in Minnesota, gold miners in South Dakota, iron miners in Norway, and iron miners in Labrador. In all of these mining areas there is definite evidence of amphiboles being present in the ore bodies. In each there are reports of the minerals being present as "fibers", which when subjected to mineralogic study, are reported as being acicular particles. In none of the populations has there been long-term quantitation of cumulative levels of exposure to such "fibers". One can infer, however, that since dust exposures have been high enough to produce other evidence of dust-related disease such as silicosis or mixed-dust pneumoconiosis, accompanying amphibole exposures have occurred. There is also good evidence to support the similarity between exposures in the Eastern end of the Mesabi Range and those in the Homestake Mine. Since in none of these mines is there any evidence of asbestos-related disease, they provide strong evidence

against nonasbestiform amphiboles acting like commercial asbestos, even when in elongated particles. The Homestake evidence is particularly strong because of its long period of operation, the documented evidence of relatively high dust exposures prior to the 1950's and the conclusive evidence of silicosis. Although there is corresponding evidence from Minnesota where exposures are found which are similar to those at Homestake, it is somewhat weaker because of the shorter pericd of time since they opened. Nevertheless, if there were an asbestos-effect on miner health, one would expect the leading edge to have become apparent.

The eighty-year period of operation of the Norwegian iron mine makes it an important potential source of information. The lack of any association between mining and lung cancer in reports from the Norwegian Cancer Registry and in a county-wide study by the University of Oslo are evidence against there being any asbestos-effect. Although amphibole fibers were found in the lungs of two former miners who died of lung cancer, the authors were careful not to ascribe a causal relationship in view of the absence of epidemiologic evidence. It would be very useful to have a full-scale epidemiologic study of this miner population.

Negative evidence from the Labrador mine at this time comes from review of radiographic evidence, which shows strong evidence for siderosilicosis, but nothing to suggest asbestosis. This population also should be the subject for a cohort mortality study.

SUMMARY

Four mining areas have been identified in which the ore bodies have been shown to contain cummingtonite-grunerite, actinolite, or anthophyllite in acicular fragments which meet the dimensional requirements for classification by regulatory agencies as asbestos but which are nonasbestiform. These are (1) taconite mines in the eastern end of the Mesabi Range in Minnesota; (2) the Homestake gold mine in western South Dakota; (3) the Sydvaranger iron mine in northern Norway; and (4) the Wabush Iron Formation in southwestern Labrador. Mineralogic analyses and environmental studies have confirmed that in each of these areas there have been opportunities for significant exposures to non-asbestiform amphibole particles with aspect-ratios greater than 3:1. In no case has there been evidence of an asbestos-like effect on the health of the miners based on (1) historical-prospective cohort studies of mortality in the Minnesota and South Dakota mines, as well as clinical observation in Minnesota; (2) clinical studies, cancer registry observations and a county-wide study in Norway; and (3) radiographic studies in Labrador. While continued observation of these populations is recommended, there is no indication of a need to regulate the non-asbestiform analogs of asbestiform minerals to the same degree or in the same manner as asbestos.

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